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DEVELOPMENT OF A MULTI-OBJECTIVE GOAL PROGRAMMING MODEL FOR THE EUROPEAN APPLE INDUSTRY

By

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Declaration

I hereby declare that this thesis has been composed by me and the work is my own.

August 1999 Alfredo Albin

Dedication

This thesis is dedicated to Monica, Montserrat, Manuela, and Emiliano, without whose love and support, this never would have been written, and in memory of my parents.

Abstract

Within the European Union and throughout the world, apples are an important fruit crop and the EU apple industry sustains a healthy internal and external market. Consumers demand a high quality blemish-free product, which has inevitably dictated an intensive pattern of pesticide use to control pests and diseases throughout the industry. As a consequence, apple orchards are often treated with a continuos dosage of chemical sprays during their operational life, defending the crop against insect and fungal diseases. In turn, this pattern of intensive agro-chemical management has created social, economic and environmental impacts with hundreds of millions of people being exposed to pesticides each year, both on and off farm. However, against this, the economic benefit derived by the demand for pesticides for apples in the EU has led to the development of a sector generating an approximate turnover of six billion EURO, which clearly reflects social (employment) and economic gain.

However, given the environmental problems associated with existing technologies, a collaborative European project was instigated to examine the improvements in environmental quality which might be gained through the introduction of new apple varieties, bred for their resistance to the most significant apple diseases, scab and mildew. Since such new varieties would still need to meet market requirements and would also need to be capable of delivering similar social and economic returns to the apple industry, assessing the likely success of the new apple variety involved a complex, multi-dimensional decision problem.

This study shows the development of a mathematical programming model constructed to provide a tool for overcoming this multi-dimensional problem. Specifically, a Goal Programming model was developed to allow the simultaneous appreciation of Social, Environmental and Economic Goals within the EU apple industry. In constructing this model, this study was able to test the main hypothesis of whether it was possible to simultaneously compare the social, economic and environmental components of a whole industry when goals in each of these sectors are measured in quite different units. However, the model also tests, mainly through the use of sensitivity analysis, the likely social, economic and environmental impacts that the introduction of a specific new apple variety would have for the EU apple industry. The conclusions show it is possible to successfully model such multi-dimensional problems and illustrates the bounds within which a new apple variety could create a Pareto improvement within the EU apple industry.

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Contents

CHAPTER 5

Application of the Goal Programming Model: results and discussion

CHAPTER 6

Sensitivity Analysis of Assumptions

CHAPTER 7

Conclusions and future research

List of Abbreviations

A.I. (a.i.)	Active Ingredient
CA	Controlled Atmosphere
CAP	Common Agricultural Policy
CP	Compromise Programming
DEAC	Development of the European Apple Crop
DM	Decision Maker
ECU	European Currency Unit
EIQ	Environmental Impact Quotient
EPA	Environmental Protection Agencies
EU	European Union
EXTONET	Extension Toxicology Network
FUR	Field Use Rating
G	Goal
GP	Goal Programming
Ha (ha)	Hectare
IARC	International Agency for Research in Cancer
IPM	Integrated Pest Management
LGP	Lexicographic Goal Programming
LP	Linear Programming
Kg/ha	Kilograms per Hectare
MUAF	Multi-Attribute Utility Function
MAUT	Multi-Attribute Utility Theory
MCA	Multi-Criteria Analysis
MCDM	Multi-Criteria Decision Making
MOP	Multi-Objective Programming
NISE	Non Inferior Set Estimation
NUTS	Nomenclature Units of Territorial Statistics
R	Runs of the model
RA	Regular Atmosphere
SWT	Surrogate Worth Trade Off
OR	Operations Research
UK	United Kingdom
USA	United States of America
WGP	Weighted Goal Programming
WHO	World Health Organisation
w	Weights

List of Figures

List of Tables

List of Appendices

Chapter 1
Introduction

Apple is one of the most important and oldest of fruit crops in the world (Westwood, 1982). Many ancient civilisations grew apples as an important food crop. It has been cited in The Bible and in many different documents from both ancient Greek and Roman civilisations (O'Rourke, 1994).

Apple is the common name for certain related trees of the rose family, and for the pome fruit of the trees. The apple belongs to the Rosaceae family and constitutes the genus Malus. The origin of the apple is not definitely known, but the tree originated as a result of hybridisation between several species, probably in the area of the Caucasus. Charred remains of apples have been found in the prehistoric lake dwellings of Switzerland (Westwood, 1982).

The domestic apple tree, a deciduous plant, grows mainly in the temperate areas of the world, between latitudes 40 and 50 degrees north, in Europe and North America, and between 30 and 40 degrees south in the southern hemisphere (Hinton, 1991). Production outside these latitudes is made possible where climate is modified by oceanic influences, or by altitude, such as in New Zealand. Apples require cold winters to induce dormancy and the setting of fruit in the subsequent season, and long warm summers to obtain ripening in most varieties. They are generally not suited to the harshness of continental winters, however, technology has facilitated gradual geographical expansion of the apple sector thorough the adoption of cold hardiness and frost tolerant root stock for cooler climates, and the use of irrigation and heat tolerant varieties allowing expansion into hotter drier areas. Over the last 40 years, there has been a gradual expansion in the areas under apple cultivation both in northern Europe and towards the equator (O'Rourke, 1994).

Apples are a very important fruit crop within Europe, with European apple production accounting for approximately 25-30% of world production (with the European Union[1] representing 20% of world production) (King, *et al.*, 1991; FAO Yearbook, 1997). The area under apple, pear and peach cultivation amounts to 0.5% of the total EU agricultural area (O'Rourke, 1994). There are 320,000 hectares under apple cultivation, producing 8 million tonnes per annum (1994), valued at approximately 2.5 billion ECU[2] (European Commission, 1994, C.O.O., 1994).

Since the middle of the fifteenth century scientists have been trying to improve the yield and quality of apples (O'Rourke, 1994). In addition, Millardet (1880) discovered the effects of pesticide copper on reducing diseases loss in grape, researchers and farmers have aimed to increase the level of disease control in apple crops.

During the 1960s, 1970s and 1980s, and as a result of the speed and ease of international communications, breakthroughs in one country could be rapidly detected and transferred to others. It was possible therefore, for developed countries to apply new technologies and at the same time, and as a consequence, during this period, the use of chemical inputs, such as fertilisers and pesticides, increased.

However, in the 1990s, the use of agro-chemicals, which seemed to provide a good solution for pest and disease control in fruit production, generated problems, such as a build-up of resistance, hazards for workers and potentially unhealthy residues in food. In addition to this, consumer concerns over pesticides began to rise (Penrose,

[1] The EU 12 as of 1994
[2] European Currency Unit

1995). Consequently, efforts were directed to producing apples using fewer pesticides in order to both reduce costs of production and to protect the environment. As an example, the Australian Apple and Pear Growers' Association in 1991 signed an agreement with consumer and environmental groups committing growers to the goal of reducing pesticide use by 50% by 1996 and 75% by the year 2000 (Penrose, 1995).

The market, however, demands a high quality blemish-free product, thus dictating an intensive pattern of pesticide use to control pests such as: red spider mites (*Pananycus ulmi*); coddling moth (*Laspeyresia pomonella*); canker (*Nectria galligena*); and the most economically significant diseases, such as Mildew (caused by *Podosphaera leucotricha*) and Scab (caused by *Venturia ineaqualis*) (King *et al*., 1991). By analysing annual sales of pesticides for use in agriculture at the European Union level it was possible to observe that in 1993 the total amount sold was 346.33 million kilograms of active ingredients, 50.9% of which fell into the fungicides category (Brouwer *et a.l*, 1994). The average cost of pesticides in apple, pear and peach production during 1989-90-91 was 214.8 million ECU, or 321.1 ECU per hectare (Brouwer *et al.*, 1994). Apples, pears and peaches represents 3.7 % of the total cost of pesticides in the EU 12 (Brouwer *et al.*, 1994). The share of total cost of pesticides, however, varies between European countries. The highest usage is in Portugal which uses 30% of the total, with the remaining EU countries varying between 0.5% and 7.8% (Brouwer *et al*, 1994). Apple, Peach and Pear production represents therefore one of the most intensive sectors in terms of pesticide use (Quin, *et al.*, 1996). It is also therefore becoming clear at this stage that the productivity gains made in the EU Apple industry may have been delivered through additional pressures on the environment.

1.1 A brief description of the apple industry

1.1.1 World apple production

World apple production is approximately 45 million tonnes per annum and has grown steadily in the decades since World War II (Figure 1.1). This situation is not unique to the apple, similar growth has been experienced in other soft fruit sectors, partly as a result of the increase in income levels in the industrialised West during that period (Table 1.1). The apple is the most (economically and geographically) important of the deciduous fruits, which include pears and peaches. It has however, experienced competition from increasing supplies of exotic tropical and sub-tropical fruits, such as kiwi fruit, avocados, mango and papaya (Prognosfruit, 1995; O'Rourke, 1994).

Expansion of apple markets, however, has not been uniform around the world. Particularly, rapid growth has occurred in the southern hemisphere and in formerly centrally planned economies (although statistics for these countries are unreliable). Nevertheless, the EU has remained the dominant supplier of apples since 1940s although areas under production have remained relatively constant over the last decade, partly as a result of the grubbing up[3] programme which was introduced by the community to reduce the problems of over supply in the EU apple market (Prognosfruit, 1995).

Table 1.1 World production of major deciduous fruit. Annual average ('000 tonnes)

	1948-62	1961-65	1969-71	1979-81	1986-88	1994[4]
FRUIT						
Apples	**13512**	**18175**	**28309**	**34551**	**40114**	**48559**
Pears	3926	5552	7923	8559	9633	11549
Peaches	2443	4765	6289	7254	7938	11340
Apricots	707	1070	1524	1700	2001	2521
Cherries	1214	1635	1570	1178	N/A	1590
Total	**21802**	**31197**	**45615**	**53242**	**59686[5]**	**75559**
Apples as % of Total	61.97	58.25	62.06	64.89		64.26

Source: O'Rourke, 1993; FAO Yearbook, 1994

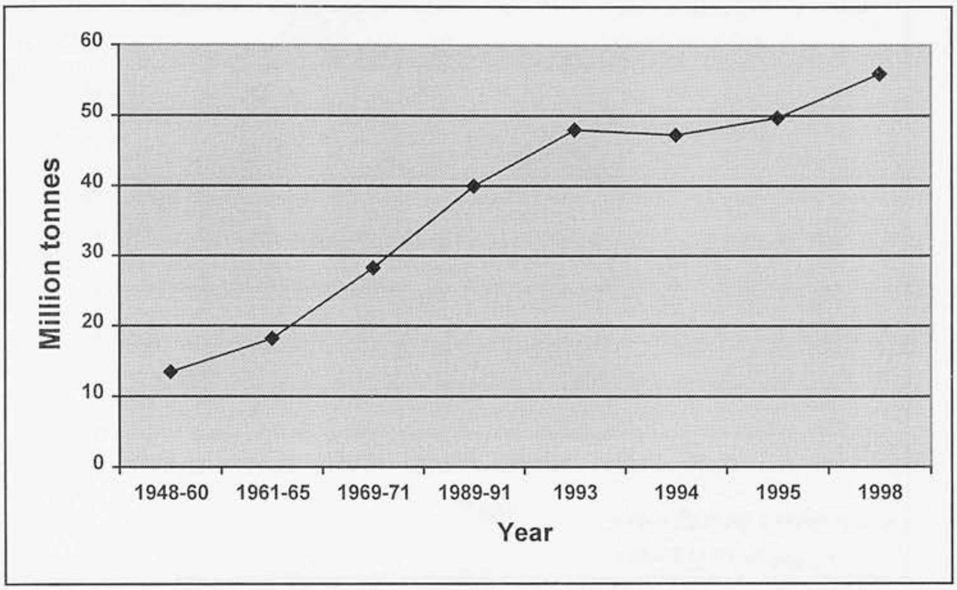
Figure 1.1 shows the evolution of apple production at the world level. From 1989 to date, world apple production has peaked between 40 and 55 million tonnes. The growth was particularly rapid in Asia, recording a rate of growth of 11.3% per year, in the period of 1971-91. Countries such as, India, Iran, Pakistan, Turkey and China have also constantly increased their apple production.

Figure 1.1 Evolution of the world apple production 1948-1995

[3] Grubbing up is simply the term used to describe the up-rooting of apple orchards to take them out of production.

[4] FAO Yearbook

[5] Ignoring missing data for cherries 1986-88

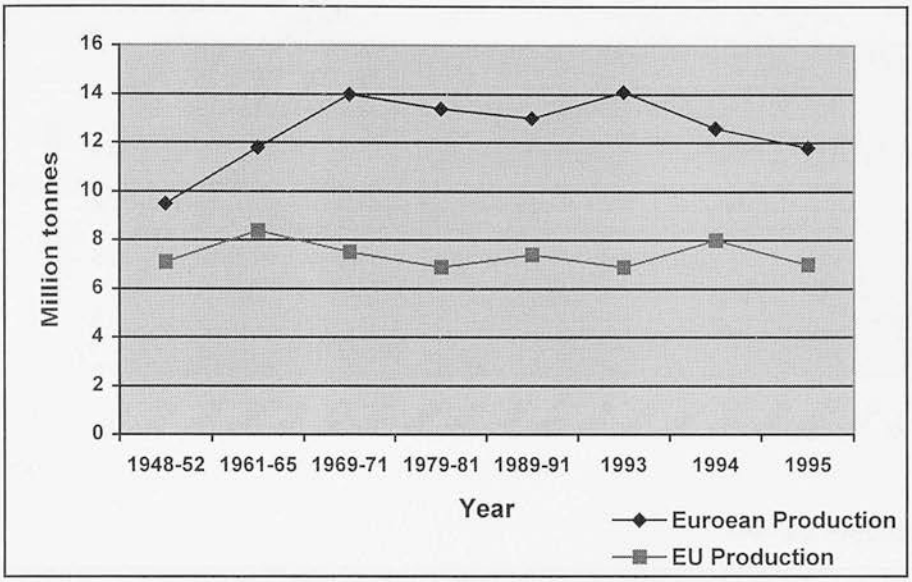


Source: Adapted from FAO Yearbook Production, 1995; O'Rourke, 1994.

1.1.2 European apple production

Europe is responsible for approximately 25% of the world's apple production. In 1993 (FAO, Yearbook, 1995) European apple production reached 14 million tonnes and since then total apple production has declined. This is shown in Figure 1.2. This reduction was in part due to the 1995 German harvest being devastated by both frost in the early part of the season and by disease. This loss accounted for 500,000 tonnes of apple in the 1995 growing season, constituting more than 50% of Germany's entire crop (Prognosfruit, 1995). The drop in production is also explained by decreasing consumer demand for apple resulting from concerns over high pesticide usage and increasing competition from more exotic consumer friendly fruits.

Figure 1.2 Evolution of European and European Union apple production.

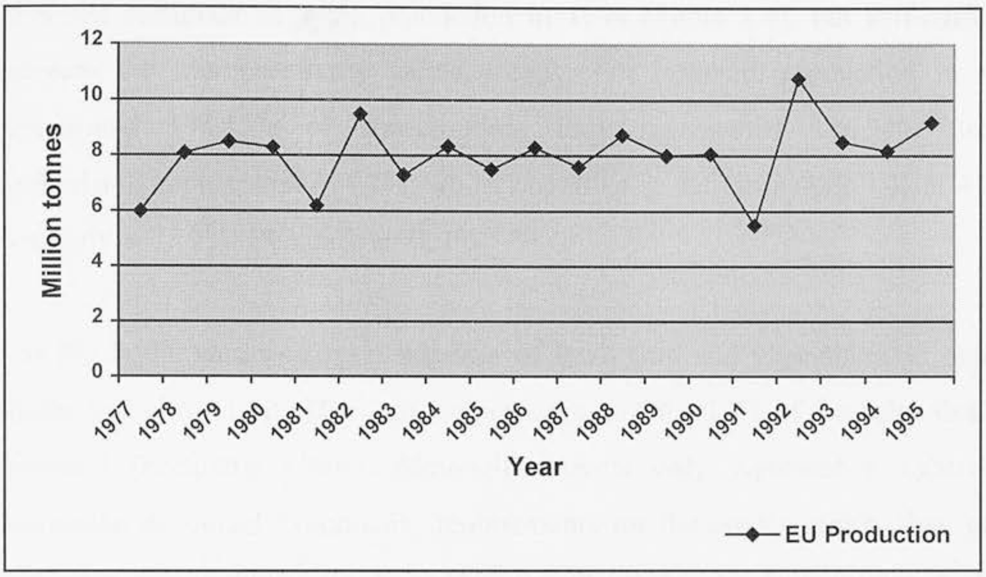


Source: FAO Yearbook, Production, 1995; O'Rourke, 1994.

1.1.3 EU apple production

Apple production in the EU (12 at 1994), as a sub-set of Europe, rose substantially between1993/4 and 1994/5 to reach 9.2 million tonnes, mainly because of major increases in Germany (+20%) and the Netherlands (+18%). By contrast, production fell in Portugal and the United Kingdom. EU apple production (as distinct from "European" apple production) accounts for approximately 20% of the total world production (European Commission, Report 1996). Figure 1.3 shows EU apple production evolution from 1977 to 1995. The most striking factor was an unprecedented level of apple production (almost 11 million tonnes) in 1992/1993. The biological phenomenon of biennial bearing was partly responsible for the great increase in German apple production. In addition, the Benelux countries and France also had quite substantial increases in production (European Commission Report; 1993, Prognosfruit, 1994).

Figure 1.3 Evolution of European Union apple production



Source: FAO Yearbook, Production, 1995; O'Rourke, 1994.

Various factors contribute to make the EU the biggest world market for fruit (and vegetables), despite its large domestic production (Hinton, 1991). Climate factors mean that it is not possible to grow fruits and vegetables throughout the year. Every year, the European Union needs to import in order to satisfy its total domestic consumption. At the same time, consumption of fresh fruit within the European Union is very high. In the particular case of the apple, the average consumption across all Member States is 19 kg per person per annum (Hinton, 1991; Prognosfruit, 1995). This partly stems from traditional dietary culture, but is also a result of both high relative incomes, and the awareness of the nutritional benefits of fruit. However, in addition, traditional trading links between European countries and former colonies, and political allies, such as Australia, New Zealand, South Africa and the USA, Brazil and Chile, also contribute in making the EU the largest world market for fruit (Hinton, 1991; Winter, 1989; O'Rourke, 1994).

Italy is still the leading apple producer in the EU (26.91% of market share), closely followed by France (26.49%) and Germany (10.94%). The EU was approximately

75%[6]self sufficient in apple production in 1994 (Table 2.6), but self-sufficiency between the Member States varied greatly. For instance, production in France represented 134.57% of consumption, Italy represented 126.34% and the Netherlands represented 114.1%, whilst countries in deficit include UK at 41.96%, Germany at 75.2%, Denmark at 72.1%.

The EU is the world's largest importer of fresh fruit and vegetables, in particular apples and citrus fruit. The apple imports account for 12% of the total fresh fruit imported (excluding citrus). Although, imports only represent a relative low proportion of annual Community requirements for the apples sector, they play an important role in supplying the market out of season and with influence to price stability during season.

EU apple exports in 1993/94 increased on 1990/91 exports by 282%. Italy is the most important exporter country. Approximately 80 per cent of the EU apple exports come from Italy (Hinton, 1991).

[6] Calculated from USDA

1.1.4 Apple Varieties

Apple orchards can remain in production for several decades, but there is, and has been, a continual abandonment of old varieties in favour of newer, higher yielding varieties (O'Rourke, 1994). The reasons for this are mainly due to changing tastes (taste, colour, shape, skin pattern, etc.).

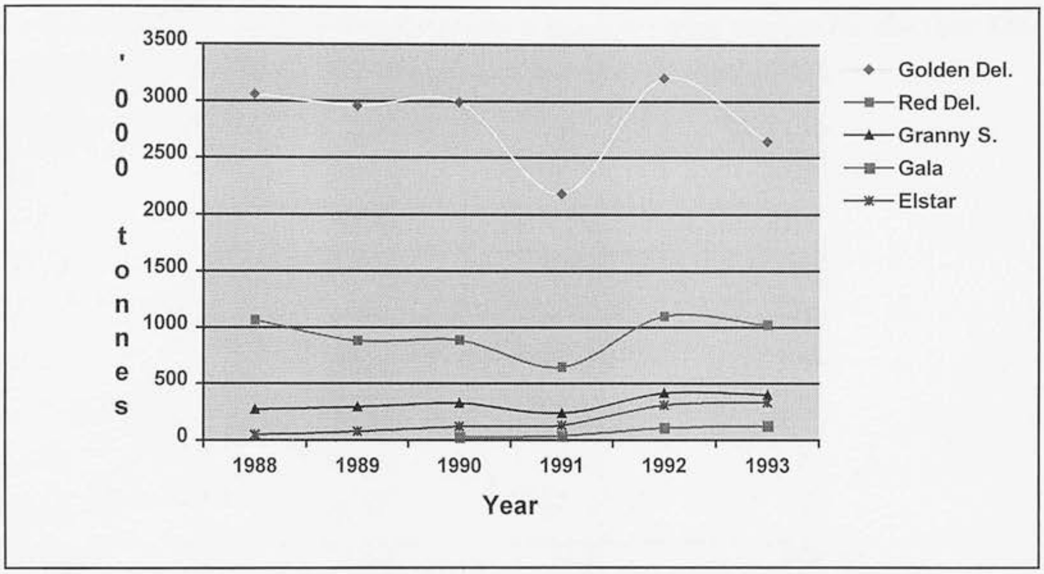
However, there is, as yet, no accepted model for predicting market preferences, and the likelihood of changes in market preference (Winter, 1989). As a consequence, the launch of a new apple variety is still a risky undertaking even with market research.

New varieties do, however, tend to have several production advantages over older varieties. This has been due to the vast amounts of money that are spent annually on the breeding of new improved varieties in research stations across Europe (King *et al.*, 1991). New varieties are bred for their ability to cope with differing climatic conditions. They are higher yielding, more disease resistant, have better storage ability and are more uniform in appearance and taste. This last point is essential in the marketing of fruit, as the consumer demands uniformity of both appearance and quality. In the mid to late 1970s the dominant variety in the world was Golden Delicious with a market share of 22.8% (O'Rourke, 1994). The same variety also dominates EU apple production, although the market share of red apples is increasing.

Nevertheless, Golden Delicious still accounts for nearly 39% of the European Union market share but evidence tends to suggest that its market share is set to drop considerably over the coming years (see Figure 1.4). There was a 5% drop in 1995 from the 1994 crop, and a further 7% drop in 1994 from the 1990 crop. The variety which has experienced the most dramatic growth in recent times is Gala; a red/green apple. Sales in Gala increased growth between 1994 and 1995 by 21%, while between 1990 and 1994 there was an astonishing rate of growth of 657% (Figure

1.4). The strength of Gala apples lie in its uniformity of appearance and taste, high yielding characteristics, and its ability to withstand adverse weather conditions, such as frost.

Figure 1.4 Evolution of the main apple varieties within EU



Source: Prognosfruit 1995

1.2 Pesticide usage in the apple industry

As mentioned in the introduction to this chapter, apple production in the EU is typified by increasing intensive production practices, involving high investment costs both during the orchard establishment period and during the operational life of the orchard. It requires continuous use of chemical sprays against insects, pests and fungal diseases and, as a consequence, world pesticides sales increased by 11.2 per cent annually between 1960 and 1992.

Pesticide use in EU apple production is generally intensive (Winter, 1986, 1989), with an average total formulated product use of 74 kg/ha per year, and an active ingredient use (a.i.) of 40 kg/ha per year. The highest use rates are France (110 kg a.i./ha) and Italy (63 kg a.i./ha), whilst the lowest use rates are for Germany (9 kg a.i./ha) and Belgium (15.24 kg a.i./ha) (Quin and Edwards-Jones, 1997) (Table 1.2). The figures presented in Table 1.2 show the distribution of pesticide intensity across the major EU apple producing member States.

Table 1.2 Pesticide use in selected European apple growing regions for the year 1994.

COUNTRY	Kg / Ha	Kg a.i. / Ha	Value Million ECUs
Italy	94.50	62.66	728
France	179.35	110.13	2204
Portugal	64.40	37.64	92
UK	42.10	20.04	594
Spain	135.20	60.66	509
The Netherlands	36.40	16.25	231
Greece	64.04	30.30	141
Belgium / Lux	29.94	15.24	151
Germany	17.93	9.34	929
Denmark	No Data	No Data	190
Eire	No Data	No Data	48
EU12	73.76	40.25	5817

The type, use rates and number of, individual compounds also varies from country to country. For example, Italy uses 10 compounds, but at a relatively high rate per compound, France uses 22 compounds again at a high rate for certain compounds, whilst The Netherlands uses 19 compounds at relatively low use rates (see Appendix 1.1).

1.2.1 The reasons for current pesticide use patterns.

The variation in pesticide use within and between Member States is due to the interaction of social, biological, economic and political factors. Economic conditions, technical possibilities, and government regulations determine optimal pesticide use patterns (Oskam, 1992; Conway and Pretty, 1991; Pimentel *et al.*, 1993). Economic conditions in apple production dictate intensive pesticide use patterns in the apple growing sector. Initial investment in orchard establishment is high, with returns on that investment not beginning for between 5 and 10 years depending on apple variety (O'Rourke, 1994). The value of the crop is also high per hectare and the consumer demands high quality, and uniformity of appearance and taste. Pesticide use in the apple industry not only secures reliable yields, but also the cosmetic acceptance of the product (Fenmore and Norton, 1985). The market does not tolerate apples with scars, blemishes and discoloration.

Agricultural activity always has the potential to create pollution to a certain extent (Conway and Pretty, 1991). Since World War II, however, agriculture has undergone considerable changes with farms becoming larger, more highly mechanised and more reliant upon synthetic fertilisers and pesticides (Conway and Pretty, 1991; Oskam, 1992; The Pesticide Trust, 1992; Beaumont, 1993). Materials once used as agricultural inputs, such as manure and straw, are now sometimes considered wastes (Conway and Pretty, 1991). Also, whereas farmers were once seen as the custodians of the land, they are now perceived as contributing to habitat and wildlife destruction, and agriculture in general seen as a major source of industrial pollution (CEC, 1992).

The reasons for this include the need for a secure food source in times of hardship[7], the demand for high quality cheap food supplies, the development of technologies which support intensive agricultural practices, and agricultural subsidies under the Common Agricultural Policy (CAP).

Current pesticide use patterns have both resulted from, and contributed to, the structural changes that have taken place in agriculture during the last half century. High levels of agricultural subsidy have encouraged the intensification of

[7] initial food stockpiling after World War 2 were in response to food shortages during, and for a decade after, the War

production, and developments in pesticide technology have permitted the continued growth and success of intensive European agriculture (Conway and Pretty, 1991). Initially, high pesticide use patterns were partly a result of poor education and ignorance of the potential hazards involved (Conway and Pretty, 1991; Beaumont, 1993). More recently, however, the current over-riding reason for high pesticide inputs in agriculture comes from consumer demand for a high quality, cheap food source.

1.2.2 Pesticides and public health

Nowadays the health hazards of pesticides are well recognised. During 1980s, attention focused on the safe and proper use of pesticides and, on establishing guidelines to achieve these objectives. One of the main issues is the general lack of hazard awareness.

Hundred of millions of people are exposed significantly to pesticides each year. For example in 1990, the World Health Organisation (WHO) registered approximately 20,000 unintentional deaths due to pesticide poisoning, mostly in Third World countries (Dinham, 1993). The International Agency for Research on Cancer (IARC) concluded that the spraying of most insecticides entails exposures are probably carcinogenic. In addition, another study showed that endosulfan[8], can be dangerously high.

Unfortunately, assessing exposure is quite difficult. Chronic toxicity in particular is difficult to determine adequately, requiring long-term studies. Symptoms such as headaches, nausea, shaking and sweating could be produced by pesticides exposures (Dinham, 1993).

[8] Endosulfan is a widely-used insecticide classified as a moderately hazardous by WHO.

Those most at risk are farmers and farm-workers. However, clinical reports of pesticide intoxication have demonstrated the potential non-occupational exposure. These reports have found pesticide residues in blood serum, breast milk and urine confirming occupational and non-occupational exposure (Repetto and Baliga, 1996).

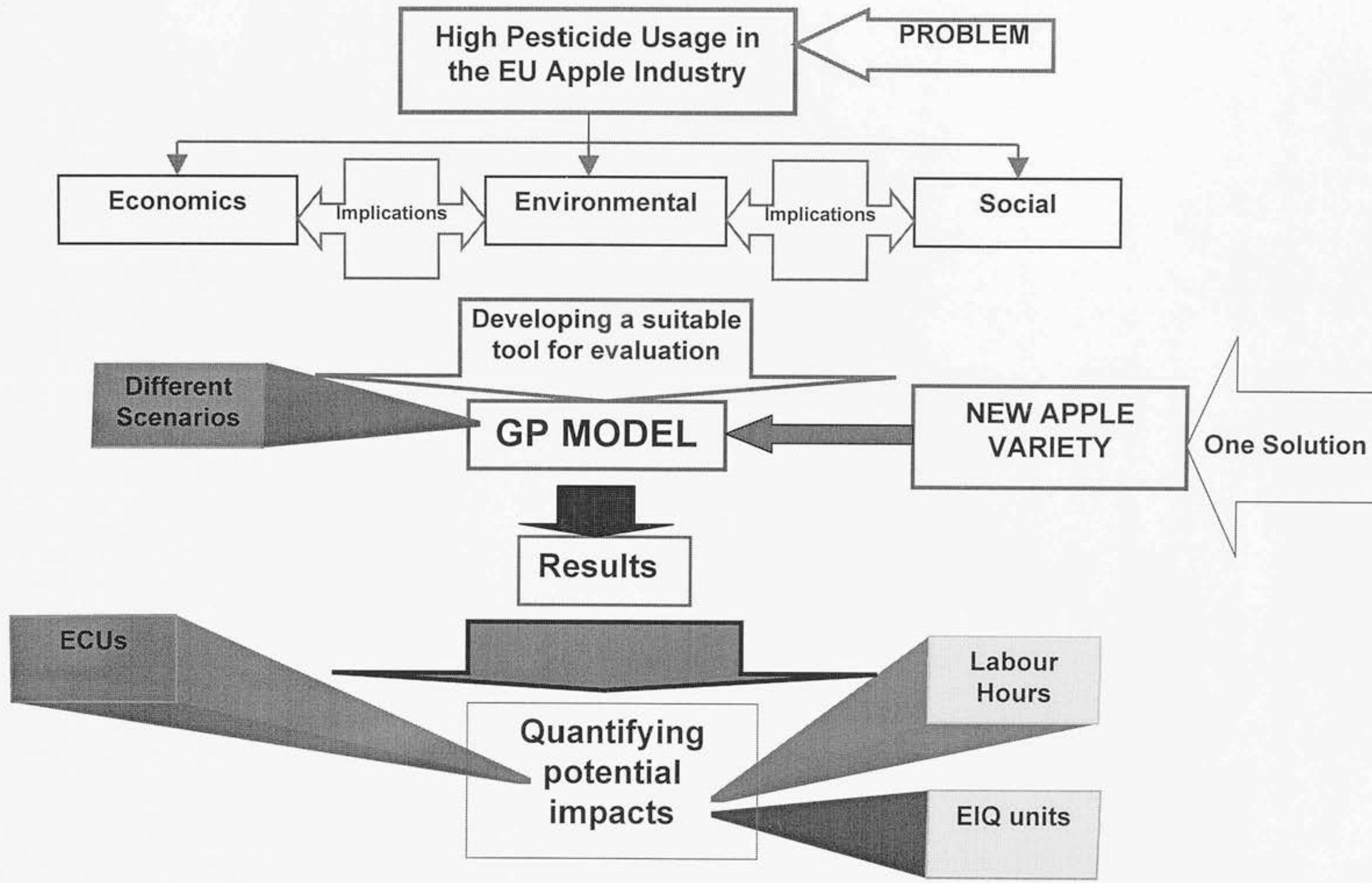
1.3 Study proposal

As discussed above, the apple industry has changed significantly in post-war Europe, and in particular in the EU, and is now characterised by an intensive pattern of pesticide use. This pattern has social, economic and environmental implications. The value of pesticides used in the EU apple industry in 1994 was almost 6000 million of ECUs (Brouwer, *et al.*, 1994). This clearly represents a sector of some significance supporting a large number of EU jobs. The EU apple-pesticide sector therefore supports some level of social condition. In addition to this, the use of pesticides in the apple sector promotes higher yields and raises economic return for farmers. However, against this, increasing pesticide use creates significant environmental damage.

One possible solution to this is to be able to develop new apple varieties which enable similar economic and social returns to be made whilst limiting the environmental damage caused by the pesticides they require (see Figure 1.5). However, evaluating such new varieties against the old, by definition, is at least a three-way criteria decision making process (social, economic, environment).

This study therefore develops a model capable of simulating the potential impact of introducing a new apple variety to the EU apple industry.

Figure 1.5 Diagrammatic illustration of the rationale of this study



1.4 Aims and Objectives

This study has been executed in conjunction with a project entitled ***"The Development of the European Apple Crop,*** *by integration of demand for high quality, disease resistant varieties suited to regional circumstances, with advanced breeding methods"* **(DEAC),** a collaborative project, funded by the CEC[9] involving plant breeders, geneticists, and molecular biologists from all over Europe. The project was funded for four years beginning in January 1993 and includes eleven institutions from seven different European countries.

The specific objective of the project is to breed new apple varieties which will meet the market demand for high quality products, whilst requiring a greatly reduced chemical input at the farm level. Thus, plants are being bred for their resistance to the most significant apple diseases, *scab* and *mildew*. There are different activities and disciplines involved in the project, from basic molecular biology, genetics and breeding to plant pathology, entomology, analysis of fruit quality and tree habit. The project also included a socio-economic and environmental perspective developed by the Scottish Agricultural College. This thesis represents the mathematical modelling component of the project.

The approach used in this thesis is the application of Multiple Criteria Decision Making methods (MCDM) suggested by Charnes, Cooper and Ferguson (1955), Charnes and Cooper (1961), Ignizio (1978), Cohon (1978), and Romero & Rehman (1989). In this particular case, a Goal Programming (GP) framework was found to be the most appropriate approach for assessing the potential economic, social and environmental impacts of the apple-breeding project.

[9] Commission of the European Communities from the AIR-3 programme (CT920473)

The model integrates economic, environmental and social parameters, to investigate the impacts of the introduction of new apple varieties into the European market.

The first objective of this research was to develop a flexible mathematical programming model, that includes economic, social and environmental parameters and which could be used to explore the impacts of the introduction of new apple varieties into the European Union on those variables.

A second objective was to assess the socio-economic and environmental impact of the DEAC project at European Community level as a result of the introduction of new apple varieties. The thesis will emphasise: utilisation of labour and variation of income at the whole EU, level of pollution and, perspectives of imports and exports from extra EU countries.

Finally the study aims to assess the suitability of the MCDM approach for assisting decision making by both researchers and policy makers at regional, national or European Union level.

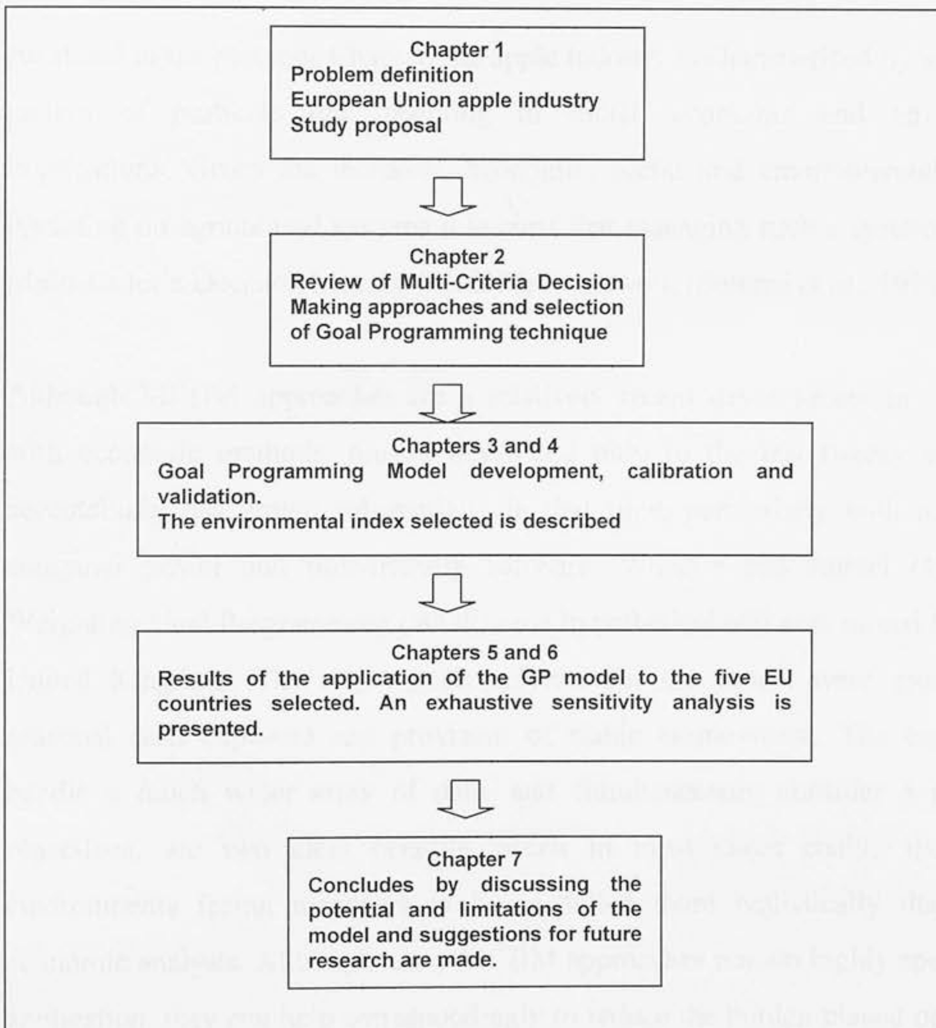
1.5 Hypothesis

- That the social, economic and environmental components of a whole industry can be compared using a single Multi-Criteria Decision-Making framework enabling the impacts of the introduction of new apple varieties into the European Union to be tested.

1.6 Summary of Thesis

The thesis is divided in 7 chapters, of which the first provides the general introduction to the study. This Chapter sets out the research problem and its objectives. In addition, a brief description of the European apple industry is presented in this chapter. In Chapter 2 the theoretical options in applying MCDM are explored and one of the MCDM techniques is identified. Chapter 3 describes the step by step development of the Goal Programming model for the European apple industry. Then, this model is validated and calibrated in Chapter 4. Chapters 5 presents and discusses the application of the model to the 5 European Union countries selected and an exhaustive sensitivity analysis is provided in Chapter 6. Chapter 7 concludes by discussing the potential and limitations of the model developed in this thesis, and includes some suggestions for future research. Figure 1.6 summarises the structure of the thesis and main contents of each chapter.

Figure 1.6 Diagrammatic illustration of the thesis structure



Chapter 2

Review of Multi-Criteria Decision Making Approaches

2.1 Introduction

As stated in the previous Chapter, the apple industry is characterised by an intensive pattern of pesticide use, resulting in social, economic and environmental implications. Given the technical, economic, social and environmental pressures operating on agricultural systems it is clear that managing such a system requires a Multi-Criteria Decision Making (MCDM) framework (Sumpsi *et al.*, 1997).

Although MCDM approaches are a relatively recent development in comparison with economic methods, mostly developed only in the last twenty years, their acceptability has grown substantially in that time, particularly with advances in computer power and user-friendly software. Wheeler and Russel (1977) used Weighting Goal Programming (WGP) on a hypothetical 600 acre mixed farm in the United Kingdom. The major goals selected for the model were gross margin, seasonal cash exposure and provision of stable employment. The capability to handle a much wider array of data, and simultaneously consider a number of objectives, are two clear benefits which in most cases enable the decision environments facing managers to be modelled more realistically than through economic analysis. Although many MCDM approaches remain highly specialised in application, they can help correspondingly to reduce the burden placed on decision-makers to process complex and diverse criteria, both by exploring alternatives and eliminating clearly inferior options (Romero and Rehman, 1987).

The presence of conflict between criteria means that solutions to decision problems will represent a satisfactory compromise rather than an optimal solution. The essential aim within multi-criteria framework is to enable the decision maker (DM) to make a decision in conformity with complex goals or objectives, as far as possible, in situations where no optimal solution is apparent (Roy, 1990)

Much of the research in MCDM has occurred in the field of Operations Research (OR). Zeleny (1982) notes that by the 1970s MCDM had become the most rapidly growing area of OR with well over 1000 articles and books having been published on the subject. There are now several textbooks, which comprehensively deal with the theoretical and practical aspects of MCDM. These include Cohrane and Zeleny (1973); Zeleny (1976; 1982; 1984); Starr and Zeleny (1977); Cohon (1978); Romero and Rehman (1989); Bana e Costa (1990) and Korhonen *et al.,* (1991).

By the mid 1970s MCDM techniques had been widely used for planning in agricultural land use, forestry as well as in water resources. Considerable literature now exists on the application of MCDM to the problem of natural resource management summarised by Romero (1993).

2.2 Categories of Multi-Criteria Approaches

Multi-Criteria Analysis (MCA) relies heavily on the use of mathematical programming techniques, which are in general formulated so as to maximise an objective subject to a set of constraint. They include techniques which generate single solutions, such as Goal Programming (GP), which require a prior specification of preferences from decision-makers; generating techniques, such as Multi-Objective Programming (MOP), which identify the set of efficient solutions to a problem, and do not require a prior specification of preferences; and iteractive techniques, in which preferences are articulated progressively through interaction between the model and the DM (Romero 1993).

A variety of categories exist for classifying MCA techniques, according to the level of preference information required, the number of solutions generated, the underlying assumptions made about the decision maker's utility function, and the number of decision-makers.

Figure 2.1 shows a classification of the principal techniques according to preference information required.

2.2.1 The elements of MCDM

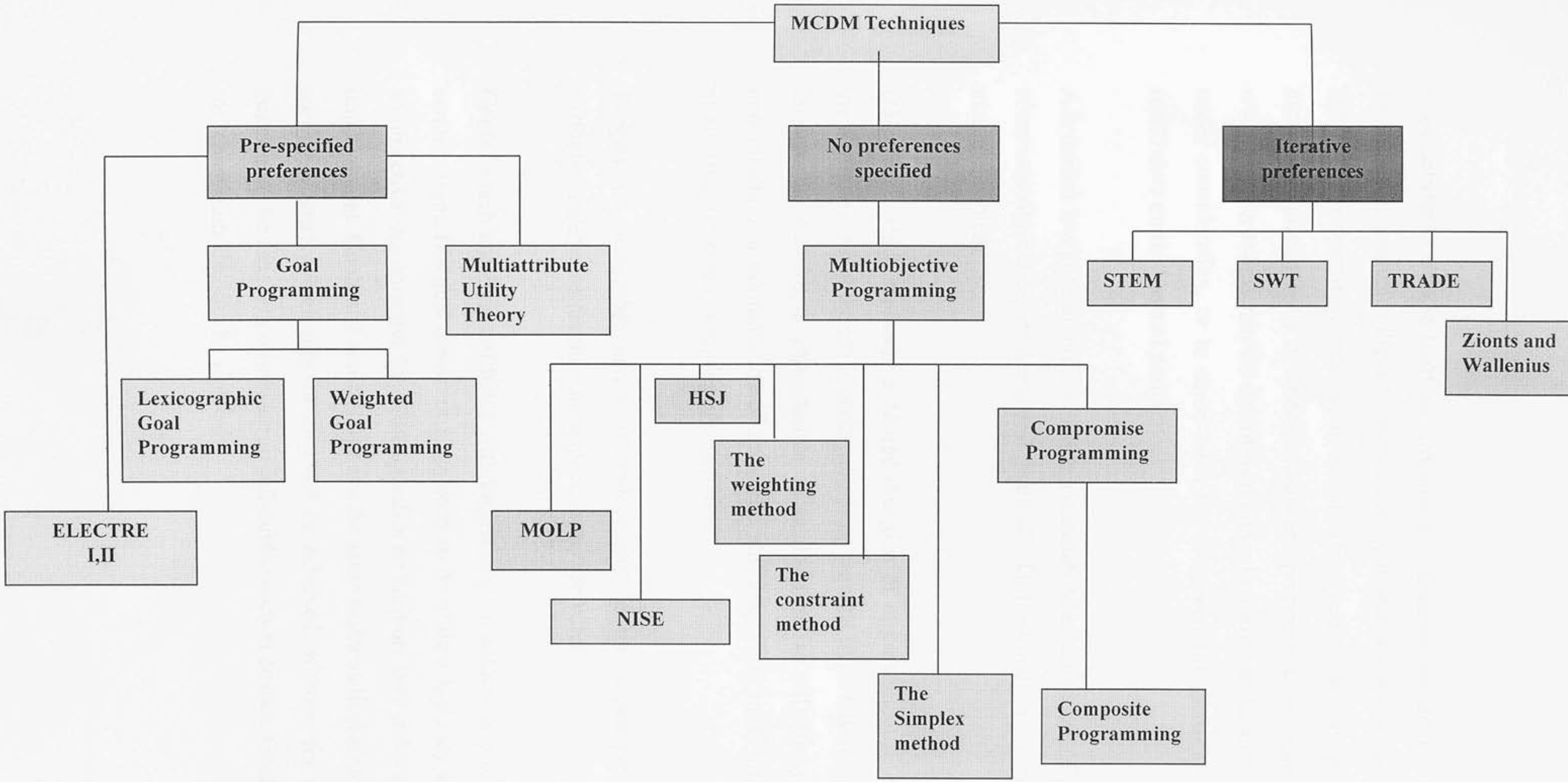
The building of an MCDM model encompasses five elements:

- decision variables;
- constraint set;
- decision criteria;
- input-output coefficients relating decision variables and constraints; and
- input-output coefficients relating decision criteria and decision variables.

The basic concepts involved in these elements can be defined as follows (Romero and Rehman, 1989; Winston 1995; Zionts, 1980):

A ***decision variable*** is any activity which can be managed through specified decisions made by a decision-maker. Hence, these values can be varied in an iterative search for the optimal mix of objective achievement, expressed by the input-output coefficients for variables and criteria. A common variable in agricultural analyses is the amount of land under different crops sown, and input-output coefficients for this would relate each area sown with a particular crop (the variable) to a decision criteria such as profit or labour hours.

Figure 2.1 Categories of the principle MCDM techniques according to preference information required



A ***constraint*** is a fixed limit on attributes and decision variables. An attribute is a measure that evaluates the achievement of goals and objectives, defined by Zeleny (1982) as a descriptor relating to an objective reality. It can be identified and measured independently of a decision-maker's preferences, an example being gross margins. Constraints may be determined either by technical features of the problem under consideration, or in some cases the desires of the decision-maker may fix constraints on the basis of preferences.

A ***criterion*** is a general term, which is a measure of effectiveness of performance. It comprises objectives, attributes and goals of a DM relevant to a particular decision making problem.

***Objectives**,* which represent a desired direction of improvement in one or more of the attributes. An objective is something to be pursued to its fullest, and is identified through the decision-makers' desires. A single objective will always be either the maximisation or minimisation of a specific attribute. Thus, maximising profits and minimising costs are examples of objectives.

Targets are acceptable levels of achievement in the improvement of various attributes under consideration for anyone of the attributes.

***Goals*,** which combine attributes with targets, e.g. to achieve a profit of at least a certain target. If a goal cannot or is unlikely to be achieved, it may be converted to an objective. An objective therefore specifies an attribute with a desired direction of improvement. Goals and constraints have the same mathematical structure; but goals specify a target which may or may not be achieved, whereas for constraints the target must be satisfied, otherwise an infeasible solution ensues. Goals are therefore soft constraints that can be violated.

In developing solutions based on these elements, all MCA methods have to develop both a definition of what represents the best solution to a vector optimisation problem, given that it is technically impossible to optimise a vector and develop a method of determining the best alternative according to this definition of best (Kazana, *et al.*, 1994). The definition of best is generally achieved by some form of priorisiting or weighting of the objectives in the model, and finding either geometric or arithmetic methods to determine it.

Solutions to multi-criteria formulations are generally approached using the concept of non-dominated, or Pareto optimal solutions. It is essential to define the concept of a Pareto optimal solution or efficient solution, because it plays a vital role within the MCDM approaches.

Romero and Rehman (1989) defined the efficient Pareto optimal solution as follows;

> *"are feasible solutions such that no other feasible solution can achieve the same or better performance form all the criteria under consideration and strictly better for at least one criterion"*,

i.e. for which an increase in the value of one criterion can only be achieved by degrading the value of at least one other criterion (Romero and Rehman, 1989).

2.2.2 Building criteria for MCDM

Building the decision criteria, which form the basis of a multi-criteria analysis, is a critical task, and a number of points should be noted. If the analysis is to function as an effective decision making tool, it must assist in producing an acceptable and efficient solution to a resource use problem. Bouyssou (1990) suggests that:

i) The points of view underlying the definition of the various criteria should be understood and accepted by all the actors in the decision process, even if they disagree on the relative importance that they would like each of them to have.

ii) Once a point of view has been defined and accepted, the method of evaluating each criterion for each alternative, should also be understood and accepted by all the actors in the decision process.

iii) The choice of a particular way to build a criterion must take into account the quality of the data used to build it.

Ensuring consensus on objectives and their measurement may itself be a substantial task in situations where there are numerous stakeholders with divergent interests. However, if the results of the analysis are credible with those affected by it, consultation and participation in the selection of criteria is critical.

Keeney and Raiffa (1976) suggest a de-compositional approach to determining the criteria for a model, with each initial objective being broken down into its constituents until an atomistic point of view or attribute to be measured is reached. The set eventually determined by this process should be:

✓ ***complete:*** if two alternatives have the same score for each criterion, then it must be agreed that the two alternatives are equivalent i.e. there should not be any further basis for distinguishing between alternatives.

✓ ***operational:*** each of the criteria should be able to be used in the analysis. This may require establishing data limitations.

✓ ***decomposable:*** two factors should not be in opposition within a single criterion.

✓ ***non-redundant:*** no aspect of the problem is accounted for more than once. If objectives are double-counted, the determination of trade-offs and priorities between them becomes blurred.

✓ ***minimal:*** no smaller set of criteria that satisfy these conditions should be available. Reducing the number of criteria as far as possible is clearly efficient of time and resources and clarifies the structure of the final analysis.

In conclusion, Ackoff (1977) notes that;

> *"an optimal solution to a model is not an optimal solution to a problem unless a model is a perfect representation of a problem".*

The possibility of perfection in building a model is clearly unattainable, but accuracy as far as possible in construction is clearly a prerequisite for an adequate analysis.

In agricultural planning, it is useful to build decision-making models capable of approximating the current situation in a given area. For example, in problems related to allocation of water and soil salinity, such as those found by Moore *et al.,* (1974) and Gardner and Young (1985), where the current situation is simulated by a linear programming model in which net farm income is maximised. The results obtained with these approaches are not usually very accurate, producing solutions which deviate considerably from the current allocation of enterprises, (Zerki, and Romero, 1992). The reason of these deviations is due to the actual behaviour of farmers being better represented by a set of objectives rather than a single one (Romero and Rehman, 1989).

2.2.3 Informational demands in MCDM

One advantage of an MCDM approach is the ability of the methods to handle both qualitative and quantitative data as inputs for analysis. The qualitative inputs will comprise not only evaluative data but also the weights and priorities expressed by the decision-maker.

Romero and Rehman (1985) suggest that;

> *"perhaps the greatest difficulty in the widespread use of the multi-criteria decision-making paradigm is the availability of the substantial information required from the decision maker on his objectives, goals, targets, weights and pre-emptive ordering of preferences".*

The role of sensitivity analysis in exploring alternatives is also an important feature of most approaches that allows a heuristic approach to determining a satisfactory solution.

The principal analysis approaches, including Goal Programming, Multi-Objective Programming, and Compromise programming, are now reviewed and their advantages and disadvantages discussed.

2.3 Principal MCDM techniques

2.3.1 Introduction

The conventional LP approach which optimises a single objective has been thought to be sufficient for dealing with decision problems in agricultural production systems (Dent *et al.*, 1986). However, in many situations decision-makers (DM) are faced with several objectives simultaneously and no single easily definable criterion exists.

Given the technical, economic, private, social, political and environmental pressure operating on agricultural systems it is clear that managing such a system requires a MCDM framework (Sumpsi *et al.*, 1997).

Under such circumstances, MCDM techniques permit optimisation of many objectives, some of which may be in conflict rather than force the model into the strait jacket of single objective optimisation (Piech and Rehman, 1993). The analysis of problems involving MCDM has been perhaps the fastest growing area of OR and Management Science during the last 25 years. Considerable literature exists on the application of MCDM techniques to the management of natural resources such as fisheries, agricultural land, forestry and water (Romero and Rehman, 1987, 1989; Romero, 1993).

In this specific study, as identified in Chapter 1, more than one objective needs to be taken into account. For each objective, there are target levels that have to be achieved and there are economic, social and environmental targets. Thus, MCDM seems to be a suitable choice for dealing with this new technology evaluation.

The most widely used techniques within MCDM are briefly described in the following sections.

2.3.2 Goal Programming

2.3.2.1 Introduction

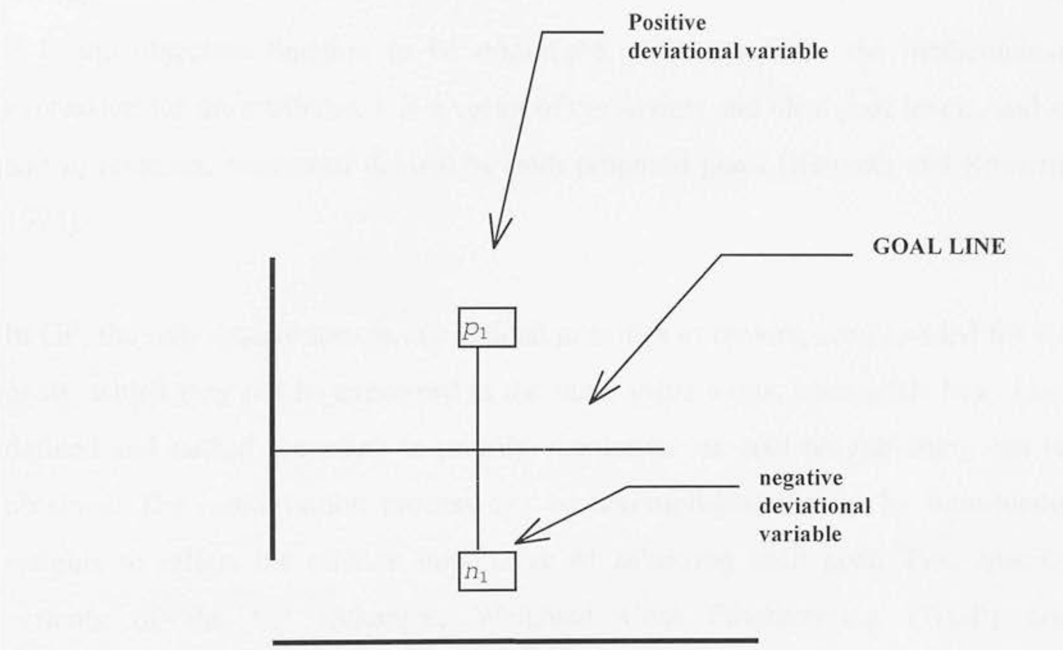
Goal Programming (GP) was first developed as a planning technique by Charnes *et al.,* (1961), and extended by Ignizio (1978), Romero and Rehman (1985) and Romero (1991). The application of GP in decision-making processes associated with resource allocation in agriculture at farm and regional level has become widespread (Romero, 1993; Dent and McGregor, 1993; Fiske *et al.,* 1994; Berbel, *et al.*, 1992; Berbel and Zamora, 1995). It has been found to correspond well with the usual understanding of the resource manager's decision-making processes: those of goal setting and goal ranking. As an MCDM technique, it is seen as the method that operationalises the Simonian "satisfying" approach as opposed to the optimising technique to achieve objectives. Simon (1955) surmises that in today ´s complex organisations the environment is characterised by incomplete information, limited resources and conflicts of interests. This author concludes that under this environment the DMs try to achieve a set of goals as close as possible with respect to a set of targets defining as well their behaviour. Therefore, the GP approach supplies a successful framework to operationalise this kind of Simonian philosophy of satisfying (Romero, 1993). The GP technique adopts a linear programming formulation as discussed by Cohon (1978) which is represented in Figure 2.2.

Figure 2.2 Goal Programming Formulation (from Bartlett *et al* 1976)

Management Scheme	Products (Users)	Deviational Variables		
Production Rate for Goal Constraints of Variable Resources	Use Rates for Goal Constraints of variable Resources	Link Matrix between Deviational Variables and Goal Constraints	=	GOAL LEVELS
Link matrix between Production of Factors on fixed resources and Management Schemes	Null Submatrix	Null Submatrix	≤	Fixed Resources (Land, Supplement)
Production rates of Variable Resources	Use rates of variable resources	Null Submatrix	≥	Lower limit of Variable resources
Null Submatrix	Link Matrix Between users and requirements	Null Submatrix	≥	Quality of user (Product) Requirement
		Objective Function of Weights and Priority Factors for the Minimisation of the Deviation from each Goal		

GP aims to minimise the deviations between the desired target levels of achievement for each objective, and the levels that can be achieved in practice, given the need to satisfy targets for other objectives. The inequalities which specify the constraints to a conventional optimisation function are therefore converted to equalities through the addition of positive and negative deviational variables. Changes in the value of these deviational variables then permit either under or over-achievement of each goal. This is represented in Figure 2.3.

Figure 2.3 Goal and deviations



The goal line represents goal attainment. The positive deviational variable (p_1) reflects by how much the target has been surpassed. On the contrary, negative deviational variable (n_1) measures the extent by which the achievement of a goal has fallen short of its target.

Algebraically the GP problem is given by:

$$Min\ Z = \sum n_i + \sum p_i$$

$$A \lesseqgtr b_j \qquad j = 1....m$$

$$subject\ to \qquad A(x) + n_i - p_i = b \tag{2.1}$$

$$x,\ n_i,\ p_i \geq 0$$

where,

Z is the objective function to be minimised, $A(x)$ represents the mathematical expression for the attributes, b is a vector of constraints and ideal goal levels, and n_i and p_i represent vectors of deviations from proposed goals (Rehman and Romero, 1993).

In GP, the only requirement is that ordinal priorities or ranking are provided for the goals, which may not be expressed in the same value terms; once goals have been defined and ranked according to priority, a solution via goal programming can be obtained. The minimisation process can be accomplished mainly by introducing weights to reflect the relative importance of achieving each goal. Two specific variants of the GP technique, Weighted Goal Programming (WGP) and Lexicographic Goal Programming (LGP) are widely discussed (Romero and Rehman, 1989).

2.3.2.2 Weighted Goal Programming

The WGP approach is used when non-pre-emptive weights are used and it takes all goals into account simultaneously in a composite objective function composed of the sum of all deviations among the goals and their aspiration levels. The deviations, however, are weighted according to the relative importance of each goal to the decision-maker. The role of weights is to express the importance of each attribute relative to the other (Yoon and Hwang, 1995). Mathematically, the problem becomes the same as the conventional linear programme and can be solved using the Simplex method developed by G. Dantzig in 1947 (Winston, 1995).

The general structure using WGP is given as:

$$Minimise \sum_{i=1}^{n} (w_1 n_i + w_2 p_i) \tag{2.2}$$

$$subject\ to, \quad f_i(x) + n_i - p_i = b_i$$

$$and, \quad x \in F$$

$$x \geq 0,\ n \geq 0,\ p \geq 0$$

Where, $\boldsymbol{n}_i$ and $\boldsymbol{p}_i$ are the negative and positive deviational variables attached to the ith attribute and w_1 and w_2 are the relative weights attached to the deviational variables. $f_i(x)$ is a mathematical expression of the ith attribute, b_i is the target set for the ith attribute, X is the vector of decision variables and $\boldsymbol{F}$ is the region satisfying rigid constraint (the feasible set) (Romero, 1991; Rehman and Romero, 1993).

2.3.2.3 Lexicographic Goal Programming

Lexicographic Goal Programming is used when attaching pre-emptive weights (weights that are elicited from the decision-maker prior to running the model) or absolute weights to the sets of goals situated in different priorities. Hence, the LGP technique assumes that the decision-maker can define all the goals relevant to the decision and give pre-emptive priorities to the goals. In this case, the fulfilment of the goals in a specific, Q_i is considered before any of the goals situated in a lower priority, Q_j. The higher priority goals are solved first, and only if they can be satisfied does the model move on to consider further goals.

The structure of this lexicographic minimisation process is given as:

$$Lex.Min.\, a = [h_1(n,p), h_2(n,p), \ldots, h_k(n,p)]$$

$$Subject\ to: \quad f_i(X) + n_i - p_i = b_i \tag{2.3}$$

$$\text{and} \quad X \in F$$

$$x \geq 0,\ n \geq 0,\ p \geq 0$$

where,

Lex.Min is the lexicographic optimisation process, and h_k the priority involving a given combination of elements for the *n* and *p* vectors. The explanation of the rest of the model structure is the same as WGP, (Romero, 1991; Rehman and Romero, 1993).

Where two or more goals are considered to be of equal priority, they can be weighted within that priority band in the same way as WGP.

2.3.2.4 Goal Programming in Application

The solution to a goal programming problem is approached within a given decision environment represented by a model, which specifies the relationship between changes in the decision variables and corresponding levels of achievement of objectives. In a continuos problem context, the variables can take any values within given constraints; in a discrete problem setting, the performance of a set of specified decision variable values, each set representing a single plan of action or scenario, is assessed with respect to the objective function.

A GP analysis will then proceed through the following steps:

1. Awareness of problem
2. Specification of objectives
3. Selection of indicators (assessment criteria)
4. Specification of constraints (rigid)
5. Specification of target levels for objectives (flexible)
6. Determination of priority order for goal achievement (LGP) or weighted priorities (WGP)
7. Where two or more goals exist at the same priority level, determine individual weights within the priority level (LGP)
8. Determine the direction of deviation change preferred
9. Determine permissible levels of deviation
10. Run model
11. Conduct sensitivity analysis by varying weights and priority levels

The allocation of priorities or weights ensures the highest priority is pursued first, the second priority goal, and so forth. In the pursuit of each subsequent goal, changes might occur regarding earlier goals. If this change is a continued minimisation of that goal's deviation this is allowable; if not, then conflict arises, and the pursuit of the minimisation of the latter goal cannot be attained (as it would require reducing the attainment of a higher priority goal). The final solution is given once the pursuit of all goals has been achieved, whether or not they have been attained as desired. If there is a no-conflict optimal solution for the model, all deviations will have been minimised and will be zero.

2.3.2.5 Goal Programming in Farming Systems

Farming systems are more complex than single enterprise models, farm business decision making involves more than one objective and often more than one decision maker, and policies are increasingly being tied through cross-compliance to environmental as well as agricultural production outputs. GP can handle the multidemensional structure of such farming systems and the associated linkages that the farming system has with the exogenous systems within which it is set (Romero and Rehman, 1984; Veloso, 1990; McGregor, *et al.*, 1996).

The origins of MCDM can be traced back to the field of OR, which was originally designed for studying highly structured problems, and in which LP was the most commonly used technique. Most of these applications were involved with private resource allocation problems, generally aimed at cost minimisation or profit maximisation subject to other constraints (Beneke and Winterboer, 1973).

Applications of MCDM within agriculture utilised weighted and lexicographic GP to assess farm objectives such as gross margins, seasonal cash exposure and stable employment, under variable combinations of crops and management approaches (Wheeler and Russell, 1977; El-Shishiny, 1988; Fiske *et al.*,1994 and de Koeijer *et al.*, 1995). de Koeijer *et al.*, (1995) applied Multiple Goal Programming[10] approach in order to provide more insight into the exchanges between income and environmental pollution of several farming systems in the Netherlands.

Field (1973) also applied GP in a forestry management context, encompassing financial, recreational and timber production objectives. The GP approaches have remained popular amongst analysts, being applied also in fisheries and water resources management.

McGregor and Dent (1993) applied a lexicographic GP model for allocation of water from the Rakaia River (New Zealand). In this particular study, the authors had to deal with fish, wildlife and recreational uses of the water river. The model was found to be effective in determining how resources should be utilised and in

[10] Multiple Goal Programming is a hybrid approach between GP and MOP, (Romero and Rehman, 1989)

determining the impacts and trade-off that would occur as a result of varying decisions about the resource, as well.

Rehman and Romero (1987) developed a GP model for of livestock ration formulation. They criticised the use of LP paradigm due to its mathematical rigidity and penalty functions were included in the model.

Minguez *et al.*, (1988) determined the optimum fertiliser combination through a GP model with penalty functions. This study was developed for sugar beet production in Spain. The nutrient requirements of sugar beet, under GP, were changed from fixed values to be considered as target that the farmer aspires to.

van Berlo (1993) used a GP model as a decision support tool for the vegetable processing industry. He considered three components as part of a logistical chain, i.e. market, industry and agriculture. A trade-off was made between meeting demand, utilisation of available cultivation capacity, utilisation of available processing industry and sowing cost.

Nkowani, (1996) applied a multiple objective programming approach to investigate land/resource use options open to smallholder farmers in the Northern Region of Zambia.

Nhantumbo (1997) developed a multi-objective model for the rural land-use planning in Mozambique, integrating agriculture, forestry and animal husbandry activities within a farm planning framework.

More background information about the MCDM –GP approach in agriculture and in other sectors is provided by authors such as Romero (1993).

In the United States, the Water Resources Council accepted the multi-objective planning approach in the early 1970s, leading to the development of a large number of multi-objective programming (MOP) systems and approaches and recognising that river basin planning authorities must consider at least environmental quality along with economic efficiency as objectives of water resource planning. This includes the SWT method which was developed by Haimes and Hall (1974) while designing a water reservoir. Goicochea *et al.* (1976) established TRADE while resolving a planning problem in Charleston watershed in Southern California. Similarly Cohon *et al.*,, (1979) developed the Non Inferior Set Estimation (NISE) method to generate a non inferior set for problems involving two objectives.

At the same time, the First International Conference on MCDM was held at the University of South Carolina, with the proceedings published in 1973. More than 60 papers were presented and a special interest group formed which established a regular series of World Conferences on MCDM.

In a study by Teckle (1992), more than 70 MCDM techniques were identified and a selection of 15 reviewed through multi-criteria analysis for their applicability to water resource management. The choice of a particular approach was seen to be a function of the type of problem, the characteristics of the decision-maker, and the type of solution required. However, given the complexity of some MCA methods, the familiarity of the analyst with a particular technique was cited as a primary factor in its selection, even if an alternative approach might have been more suitable. Correspondingly, familiarity was seen as an important aspect of the successful application of the technique.

It should be noted that although Teckle's study identified two preferred techniques (Compromise and Composite Programming), the complexity of multi-criteria scenarios suggests that no single approach will be superior in all circumstances.

2.3.2.6 Limitations and strengths of goal programming technique.

A substantial literature has grown up regarding the limitations and strengths of the GP technique (Bishop, *et al,* 1977; Ignizio, 1981; Zeleny, 1981; Barnett, *et al*, 1982; Dyer *et al*, 1979,1983;Steur, 1986; Romero and Rehman, 1989; Veloso, 1990; Romero, 1991; Rehman and Romero, 1987; Rehman and Romero, 1993, McGregor *et al*, 1994). Goal Programming was found to have the following advantages by some of these authors;

GP can incorporate the advantages of generating techniques and it presents computational efficiency in comparison to the generating techniques, particularly for solving WGP models for which an access to the standard Simplex model is sufficient (Steur, 1986).

In addition, GP provides a logical and easily understood process of analysis, proceeding from goal definition to achievement in an orderly manner. Although much work is required in the construction of the model, the analyst must correspondingly understand the problem in great detail and a more reliable definition of the interactions taking place may therefore result. GP can also incorporate a measure of risk into the programming routine.

However, although GP is a powerful tool which combines the logic of optimisation in LP with the decision maker's desire to satisfy several goals there are a number of difficulties in the use of the method which should also be noted:

Although trade-offs between goals can take place within a given priority they cannot be traded off across the boundaries of different priorities.

The requirements for preference information from the decision-maker (for example; aspiration levels, weights to be attached to unwanted deviation) are very exacting and sometimes are subjectively applied (Harrald *et al*., 1978). In the case of WGP, the assignment of weights is a difficult task and the restrictiveness of the priority levels in LGP make careful assessment of preferences important and, it can be difficult to establish targets which are representative of the true aspiration levels of decision-maker. Nevertheless, Piech and Rehman (1993) suggest that targets be derived from a conventional linear programming solution as the optimal values of the objective function for each goal, or be set slightly higher.

In the case of LGP, it has been shown that a lexicographic ordering cannot be represented by a real-valued utility function (Debreu, 1959). It has been suggested therefore that LGP may not in some cases optimise the decision-maker's utility function (Harrald *et al*, 1978).

In addition, when the number of priorities is larger than five goals in the lowest priorities can become redundant. This problem can be addressed by using fewer priority levels and non-pre-emptive weightings for goals within levels.

Romero and Rehman (1987, 1989); Rehman and Romero (1993) and Romero (1991) point out that there are methods available which help to reduce the difficulties to be faced with the use of GP. For instance, the use of sensitivity analysis and the interactive use of GP are recommended when the decision maker is not confident about any of the parameters of the model. Thus, the use of sensitivity analysis should be an integral part of the model implementation process (Nkowani, 1996).

2.3.3 Compromise Programming

2.3.3.1 Introduction

Compromise Programming (CP) is a method proposed by Yu (1973) and Zeleny (1974) to help the decision-maker choose the optimum solution from the efficient ones generated by MOP. Romero *et al.*, (1987) and Zekri and Romero (1993) applied CP technique for agricultural planning and agricultural water management respectively in Spain. The optimal solution in CP is given by the point which lies closest to the what Zeleny terms the "ideal" solution point- the point given by the optimum values of various objectives of the decision maker when each is optimised individually. By this method, the solution is derived by reference to the technical constraints of the problem situation, as expressed by the ideal objective values, rather than by any a *priori* specification of preferences by the decision-maker.

If the ideal point is in fact feasible then there is clearly no conflict among the objectives. However, the ideal point is usually infeasible, therefore resulting in conflict and the need for trade-offs among objectives. CP thus defines as optimum (or best compromise solution) the efficient solution that is closest to the ideal point.

The notion of distance is used here as a "proxy for human preference"; depending on the particular measure of distance used, a set of compromise solutions can be established (Romero and Rehman, 1987).

The ideal point can be found from the pay-off matrix of objective function values obtained when each of the problem's objectives is maximised individually. An example of a pay-off matrix is illustrated in Table 2.1

Table 2.1 Pay-off Matrix for establishing ideal and nadir points. (From Romero *et al.*, 1987)

Objective function	Gross Margin/£/ha	Employment/hrs/ha
Gross Margin £/ha	**100000 (max)**	80.000 (min)
Employment Hrs/ha	300 (min)	**400 (max)**

In this example for a two criteria model, the major diagonal of the resultant square matrix gives the co-ordinates of the "ideal point". The minor diagonal gives the anti-ideal, or "nadir" value, when all objectives take their lowest value. Thus for *n* criteria, an *n*-dimensional square matrix can be constructed which will contain the values required for establishing the ideal and nadir points.

These two points in vector space reveal the extent of the conflict between different objectives and define a set between them. Both lower and upper bounds of this set can then be used to normalise values for each objective relative to a common standard.

Zeleny's axiom of choice (Zeleny, 1973) states that a rational decision-maker will prefer the problem solution that lies closest to the ideal point as defined by the pay-off matrix. Thus the ideal point represents the best-compromise solution to a multi-objective problem. The degree of closeness of any particular objective value to the ideal value for that objective is given by the difference between the ideal and actual values:

$$d_j = z^{max} - z(x) \qquad [\textit{for maximisation}]$$

$$\text{or} \qquad (2.4)$$

$$d_j = z(x) - x_{min} \qquad [\textit{for minimisation}]$$

where d_i is the degree of closeness between actual achievement of the *j*-th objective and the ideal value, either *zmax* or *zmin*. The degree of closeness between actual and ideal values for different objectives can then be aggregated to form a composite distance function. The values entered into the composite function must first be normalised, however, by reference to the pay-off matrix values. This can be achieved through the highest common factor method, and the degree of closeness for any particular objective is then given by:

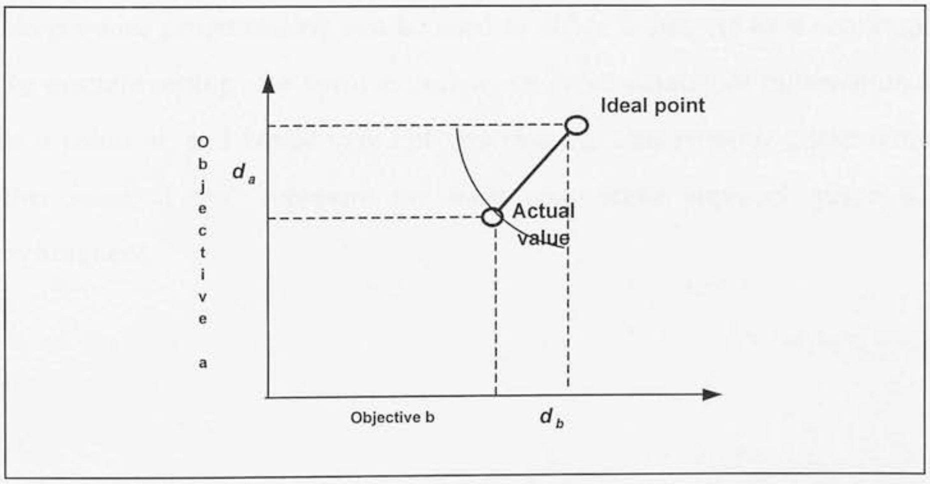
$$d_j = \frac{z_j^{\max} - z_j(x)}{z_j^{\max} - z_j^{\min}},$$
$$or \tag{2.5}$$
$$d_j = \frac{z_j(x) - z_j^{\min}}{z_j^{\max} - z_j^{\min}}$$

Chosen so that the value of d_j is always positive. The value of d_j is then expressed as a relative measure of divergence for each attribute.

It is important to recognise that this normalisation will hide absolute differences in magnitude between attributes measured on similar scales. It is important therefore to ensure that either all attributes are in different scales, or the correct relative weight is explicitly acknowledged through the standardisation process.

For a two-objective model, the results of this analysis can be shown graphically, as in Figure 2.4

Figure 2.4 Graphical representation of divergence between ideal and actual values



The specification of the distance function is obtained from the equivalent of a two-dimensional Euclidean distance function developed for a n-dimension space. The standard form commonly used for this metric is given by:

$$L_p = \left[(\sum w_j . d_j)^p \right]^{1/p} \qquad (2.6)$$

where w_j represents the relative weight or importance of the degree of closeness, d_j, of the j-th objective to the ideal, and the parameter p indexes the importance of the magnitude of deviation of the objective value from the ideal. The index p thus gives the power of the metric: the L1 metric represents the minimum solution, minimising the sum of all deviations; high values of p (approaching the $L\infty$ metric) yield the minimax solution, minimising the value of the maximum deviation. For different sets of the weights w and indices p, different compromise solutions can be obtained. When the number of objectives under consideration is greater than two a graphical representation of possible solutions is clearly impossible; however, Composite Programming retains the graphical display of results by reducing the final number of objectives to two through a progressive aggregation of lower order indicators.

Compromise programming can be used in either a discrete or a continuous setting. The discrete setting may involve limitations in the amount of information considered for a solution, and hence may not generate the best possible compromise. On the other hand, it may represent the most appropriate approach given a particular environment.

2.3.4 Multi-Objective Programming

2.3.4.1 Introduction

In problem situations where preference information is scant or non-existent, it may not be possible to order the objectives as suggested in the goal programming approach. Multi-objective programming (MOP) or vector optimisation techniques are therefore designed to tackle the simultaneous optimisation of several objectives for which the direction but not the magnitude of objective achievement is specified (Mendoza *et al.*, 1986; Romero and Rehman, 1987). Since in the absence of prioritising or weighting an optimal solution is undefined for multiple objectives, MOP approaches generate the set of efficient solutions to a multi-criteria problem.

The efficient set will lie along the boundary of the production possibility frontier, and separates the Pareto optimal feasible solutions from the non-Pareto optimal ones. In the absence of other selection criteria, the identification of the efficient set as the starting point for decision analysis requires only the assumption that increased levels of objective achievement result in higher (or at least equal) utility. If the size of the efficient set is in addition very small, this may be sufficient by itself to determine a final decision. However problems of even moderate size (involving less than fifty variables and constraints) may generate several hundred efficient points, requiring further refinement.

Extensions of MOP may then seek to define an optimum compromise for the decision-maker from among these efficient solutions. This requires some means by which the preferences of the decision-maker can be incorporated, (Romero and Rehman, 1989).

The basic mathematical structure of a MOP model is thus given as:

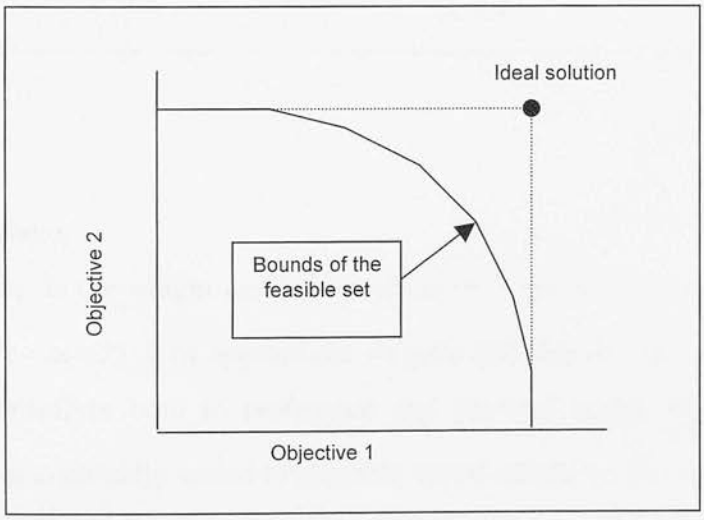
$$EffZ(x) = [Z_1(x), Z_2(x), \ldots, Z_q(x)]$$

$$\text{subject to} \quad x \, \varepsilon \, F \quad x \geq 0 \tag{2.7}$$

where *Eff* means the search for the efficient solutions (either in the minimising or maximising sense) and *F* represents the feasible set (Romero and Rehman, 1987). The model of the decision environment under MOP is therefore less rigid than under GP and requires only the identification of objectives.

With two objectives, the boundaries of the feasible set can be represented graphically by plotting the set of constraints given in the multiobjective model. The graph for the two objectives is then a geometric representation of the decision variable space. The gradient of the line segments forming the boundaries of the feasible set gives the trade-off functions between the two objectives (see Figure 2.5).

Figure 2.5 Graphic representation of MOP model



Basically there are three different approaches in order to generate or at least to approximate, the efficient set, (Romero and Rehman, 1987). They are;

- Weighting method,
- Constraint model and,
- Multicriterion simplex method.

2.3.4.2 The weighting method

The weighting method combines all the problem objectives into a single objective function by attaching a specific weight to each objective and then adding the resultant components. This converts the problem from a vector optimisation to a scalar optimisation:

$$Max \sum_{i=1}^{k} w_i z_i(x) \tag{2.8}$$

subject to $x \, \varepsilon \, F$

$$x \geq 0$$

where,

w_i is the weight applied to reflect the importance of achievement of objective z_i. The selection of appropriate weights will depend on the significance of particular objectives both in preference and physical terms. The weights w_i can then be parametrically varied to generate varied solutions. The weighting method converts a MOP problem to a conventional linear programme, although the summation process requires a standardisation procedure for incommensurate objective measurements, which can be achieved through the highest common factor method.

2.3.4.3 The constraint model

The constraint approach involves optimising one objective and building others into the model as restraints, again converting a vector optimisation problem into a scalar one:

$$
\begin{array}{llll}
 & Max\ z_j(x) & & \\
subject\ to & x\ \varepsilon\ F & & (2.9) \\
and & z_i(x) = b_i & i \neq j & \\
 & x \geq 0 & &
\end{array}
$$

where;

b_i are the lower bounds applied to the k-1 objectives. In formulating the initial bounds, the lowest value of achievement for each objective is taken, and these values collectively define an anti-ideal or nadir point, representing the worst possible level of objective achievement. The efficient set can then be generate by parametric variation of these bounds, provided that the constraints are binding at the optimal solutions.

2.3.4.4 Multicriterion simplex method

This involves finding all the extreme efficient points by moving from one extreme (efficient) point to an adjacent (efficient) point. It is a third solution approach but due to its high computational requirements its application is often limited to very small problems where k<3 (Romero and Rehman, 1987).

2.3.4.5 Advantages and disadvantages of MOP approach

The advantages of MOP approach can be summarised as follows.

First, MOP has low requirements for preference information from decision-makers, in cases where interaction is difficult or unique preferences difficult to obtain (Lee *et al.,* 1995). Second, it offers a wide array of alternatives for appraisal. Finally, opportunities are provided for inter-disciplinary interaction in discussion of alternatives.

Correspondingly, since the initial problem situation is less clearly defined, their disadvantages can lie in the high computational burden. In addition, possibilities of missing or inadequately formulating objectives in complex situations and, the assumption that constraints are inviolated and parameters precise and reliable, when in fact the values of these elements are "fuzzy".

In general, however, MOP methods should be seen as the first stage in any MCDM approach, which can then be extended in a number of ways through weighting and distance-based selection methods.

2.3.5 Multi-Attribute Utility Theory (MAUT)

The purpose of multi-attribute utility theory (MAUT) is to build a utility function with a number of arguments equivalent to the number of attributes under consideration. The approach is usually applied to decision problems with a discrete number of feasible solutions. Accepting certain assumptions about the preferences of the decision maker, a multi-attribute utility function (MAUF) is elicited. This function associates a number, representing utility, to each alternative and thus completely orders the set of alternatives (Romero and Rehman, 1987;1989)

A multiple attribute utility model is expressed by the form:

$$\sum_{j=1}^{j} w_j U_j(p_{ij}) \qquad (2.10)$$

where $U_j(p_{ij})$ is a measure of the utility of alternative I (I=1,2,...., I) for criterion j and w_j represents the relative importance of each criterion.

MAUT is clearly difficult to apply for group decision-making scenarios, since establishing the corresponding group utility function is likely to be very difficult if not impossible. It has received relatively little application in a natural resource planning context.

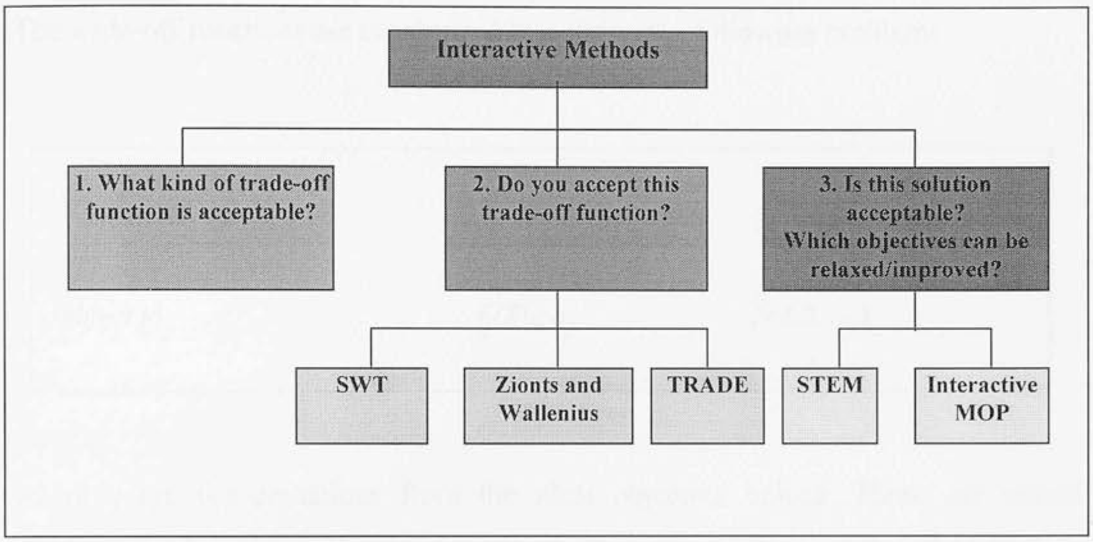
2.3.6 Interactive Techniques

2.3.6.1 Introduction

Interactive techniques seek to draw out relevant preference information from decision-makers through iterative person-machine or decision maker-analyst interactions, (Cohon, 1978). Both GP and MOP can be used in this process (Romero and Rehman, 1987), through the use of sensitivity analysis, involving the parametric variation of constraints or targets.

Techniques specifically designed for iterative preference elucidation include the Surrogate Worth Trade Off (SWT) (Haimes and Hall, 1974), TRADE (Goicochea *et al*, 1976) and PROTRADE (Goicochea *et al*, 1976) methods. These techniques identify a trade-off between objectives and offer the decision-maker successive pairwise choices until the advantages from trading are exhausted. The iterative procedure itself may progress according to three scenarios, as is shown in Figure 2.6.

Figure 2.6 Types of interactive MCA approach



2.3.6.2 Surrogate Worth Trade Off

The Surrogate Worth Trade Off approach was developed by Haimes and Hall (1974), and applied to water resource planning by Haimes *et al* (1979). The method is based on developing local approximations of a decision-maker's assumed underlying multi-attribute utility function, by examining the acceptable marginal rates of substitution amongst objectives. The emphasis is thus on defining the indifference curves that are tangential to selected segments of the non-inferior set.

The method starts by computing the ideal solution for each objective and selecting a reference objective *(f_i)* arbitrarily. Surrogate worth functions are then developed which assess the desirability of achievement of one objective comparative to another. Hence, these functions measure whether the marginal change in one objective function is worth more or less than a unit change in another.
The feasible solution set is reduced to a non-inferior set by discarding inferior solutions, for which an improvement in one objective in not possible even with a

degradation in another. The optimal solution is chosen from the remaining solutions at the point where all surrogate functions are equal to zero.

The trade-off functions are constructed by solving the following problem:

$$\begin{array}{lcr} & Max\ F_i(X) & \\ subject\ to & f_j(X) \geq \epsilon_j & j=1,2,....,k \end{array} \tag{2.11}$$

where ϵ_j are the deviations from the ideal objective values. These are varied parametrically to generate the set of non-dominated solutions. These solutions are ones which have non-zero values for the marginal rate of substitution (MRS) defining the decision-maker's valuation of the trade-off between objectives given by

$$MRS_{ej} = -\frac{\delta Fe}{\delta F_j} \tag{2.12}$$

The values of F_e are presented to the decision-maker, to ascertain the change in F_e acceptable for a unit change in F_j. The surrogate worth of each trade, w_{ej} is then given by:

$$w_{ej} = \frac{MRS_{ej}}{t_{ej}} - 1 \tag{2.13}$$

where;

t_{ej} is the trade-off value indicating the actual quantity of f_e the decision-maker gives up for a unit increase in f_j, according to the technical constraints of the model. The solution is given when this value is equal to the MRS, and the surrogate worth thus equal to zero.

2.3.6.3 Advantages and Disadvantages of Interactive Techniques

The advantages of an interactive approach clearly lie in the sympathetic attitude taken to decision-makers' uncertainty on initial priorities and the use of directed questions to try to clarify them. In general, an interactive method:

- acts as a learning process for the decision-maker, enabling him to develop a better understanding of the system under consideration,
- requires only the articulation of local preferences by the decision-maker, who has to determine an opinion only on the trade between two objectives and,
- is much less restrictive in its underlying assumptions than some other techniques

However, there are a number of problems that should be noted:

- a very major consideration is the time and effort required by the decision-maker during the iterative process. In some decision frameworks, this may be a substantial problem, particularly in a group context,
- although the model assumes "rational" choices by the decision-maker, inconsistencies have been found common in practise, particularly if the decision process is extensive, increasing the danger of inconsistent answers,
- in some methods, the convergence to a single solution may not be less than the number of efficient points and,

- some experiments suggest that interactive methods are distrusted by decision-makers, who prefer a trial and error approach (such as provided by sensitivity analysis in GP).

It should be noted in conclusion that all multi-criteria techniques can be utilised in an interactive manner by the use of sensitivity analysis in exploring the effects of changing priorities and aspirations in objective achievements. The distinction should be made between those methods that seek to elicit inputs from decision-makers as part of an heuristic approach to a solution, and those that generate solutions independently, and utilise decision-makers' inputs *a-posteriori* by re-defining a fresh set of constraints and priorities in the light of earlier results.

2.4 Advantages and Disadvantages of MCDM techniques

2.4.1 The advantages of MCDM approach

Linear programming models analyse problems by maximising a single objective, such as profit maximisation or cost minimisation, subject to a set of constraints. Traditionally, all goals are defined in a common unit. Whereas this approach ensures a single optimal solution to the problem as specified, the nature of many problems may be more accurately represented by the simultaneous consideration of a number of competing goals. Multi-criteria analysis models this feature by seeking to optimise several objectives simultaneously. MCA can therefore be seen as an extension of the traditional linear programming approach.

When the presence of conflict between several goals places a restriction on the levels of achievement reached for any particular goal, the decision-maker must adopt a strategy based on an acceptable trade-off between conflicting objectives. This recognition that any solution will represent a **satisfactory compromise** rather than an **optimal solution** is at the heart of multi-criteria decision-making. The essential aim is to enable a decision-maker to make a decision in conformity with their goals' as far as possible, in situations where no optimal solution is apparent (Roy, 1990).

MCDM techniques can therefore aid effective decision-making in at least three ways:

- by providing ranked sets of solutions, according to selected criteria, which can form one input to a decision-making process in addition to other approaches,
- by structuring the decision problem in a methodical and rational way, making the needs for information and communication clear and,
- by examining the trade-off in objective achievement between different options, and between different value systems (through the use of weights and priorities).

2.4.2 The disadvantages of MCDM approach

The conventional decision-making paradigm recognises three essential elements (Romero and Rehman, 1989):

- a single decision-maker (an individual, or a unified group),
- an array of feasible choices and,
- a recognised, well-defined criterion by which choices can be ranked for example, utility or profit).

The nature of environmental and agricultural decision making presents considerable problems with this simple model. Decision-makers must often consider the demands of many diverse groups, with different priorities and interpretation of costs and benefits, under considerable data limitations. In these circumstances the assumptions required to reduce the problems to fit the criteria above are often unwarranted, and consequently may not offer appropriate approaches to effective decision-making.

These assumptions may fail in an environmental decision context, due to both the conflict of interest between different environmental stakeholders, and the complexity of environmental data itself. It is unlikely that any one measurement scale can adequately capture differing sources of utility ranging from amenity and recreation to economic performance (Sagoff, 1988). Monetary evaluation methods which rest on such assumptions may give a false sense of precision where the underlying structure of preferences in real life is not as clearly defined as the theoretical model assumes (Vats and Bromley, 1994).

In adopting a decision-making method, managers may choose from a range of formal and informal styles. Informal styles, reliant on experience, consultation, intuition and skilled judgement, are highly flexible and impose few constraints on the kind of data entered into the decision-making process; on the other hand, they may require considerable institutional support, the creation of effective communication network, and the process of both gathering and analysing data can be haphazard and the data itself subject to misinterpretation. In contrast, formal approaches such as cost-benefit analysis offer very simple and specific decision criteria but make heavy demands on the quality of information required, and are thus susceptible both to errors in these data and in the construction of the framework within which they are analysed.

MCA techniques may be seen as forming a mid-ground on this spectrum, in which both quantitative and qualitative data inputs can be ordered within a formal framework. Whilst no single method can provide a universal panacea to solve problems of incommensurable objectives, the array of approaches developed within multi-criteria analysis can offer greater flexibility than single objective methods such as conventional linear programming.

In a situation with multiple stakeholders, MCA can also play an active role in conflict resolution, as the choice process is relatively transparent and the varied demands of interested groups, often not expressed in commensurate terms, can be explicitly addressed. In addition, interactive techniques offer the opportunity to clarify and reassess preferences and objectives in the light of suggested alternatives. This greater flexibility in accommodating "fuzziness" both in data type and in objective formulation suggest that MCDM techniques can be well-suited to natural resource management situations.

2.5 A Comparison of GP, MOP and CP

A brief comparison of GP, MOP and CP approaches can be made in relation to computational demands, preference data requirements and the number of final solutions produced:

Computational time

- GP requires a single computer run, and in this respect is the most efficient, but if sensitivity analysis regarding the targets, weights, priority order, etc., is undertaken the computer burden increases.
- MOP has the heaviest requirement for computer time.
- CP reduces the data requirement of MOP, i.e. data requirement is reduced if CP is used instead, but the method is still computationally burdensome.

Quality of information required from the decision maker

- GP is possibly the most "difficult", since detailed specification of preferences is required from the decision-maker, although sensitivity analysis permits assumed preferences to be tested.
- MOP as an expression of objectives being considered means that the decision-makers' preferences do not need to be known.
- In CP, only the relative preferences of the decision-maker need to be known.

Information produced by the model for use by the decision maker

- GP provides only a single solution.
- MOP provides an efficient set of solutions.
- CP provides the bounds of the efficient set closest to the ideal point

2.6 Conclusion

Based on the evidence given throughout this Chapter, MCDM approach used to construct the European apple model in this study is Goal Programming.
There are two main reasons for this selection:

a) Computational time

As was mentioned above, GP presents computational efficiency in comparison to other techniques. This is an important point since, as the following chapter will illustrate, the model developed is very large and time would be a limitation using other techniques. In particular, MOP has a high computational burden and for larger models, MOP is not recommended as it could lead to having too many solutions to choose from for such a large problem, which makes the ultimate analysis tend towards the subjective.

b) Information obtained.

Although GP gives only one solution, for the purpose of this study, it is possible to describe different scenarios and set up a sensitivity analysis.

With complex models, MOP produces an enormous amount of information which would be almost impossible to deal with.

Despite one of the strong criticisms of GP being that it requires a large amount of information from the DM, Rehman and Romero (1993) consider that such criticisms have no significant effect since sensitivity analysis of priorities, weighting and even change in goal levels, can be used to generate information and, therefore, reduce the amount of input from the DM.

In final defence of the selection of GP these authors also remark;

> *"as some authors have pointed out, the choice of a particular MCDM approach is in itself and MCDM problem!"*

The success of this thesis can be defined by the fulfilment of the objectives established in Chapter 1. In addition, researchers and policy makers would be the potential users of the GP model developed in this thesis. It is therefore the contention of the author here that the success of this thesis will validate the selection of GP. The following chapter, therefore, describes the development of the EU apple GP model.

Chapter 3
Goal Programming Model Development

3.1 Introduction

This chapter presents and describes the construction process of the Goal Programming model that was purposely built for the assessment of the DEAC project. The GP-matrix to simulate the EU5[11] apple industry is made up of 2,675 columns for the activities and 2,377 rows for the constraints. The model was developed using *Microsoft Excel 5.0* and solved with *What's Best 3.0* by LINDO Systems Inc. This software is useful for solving large models and it is easy to use and link with standard spreadsheet software.

3.2 Model classification

3.2.1 Defining a model

According to Jeffers (1987) in Braat and van Lierop (1987);

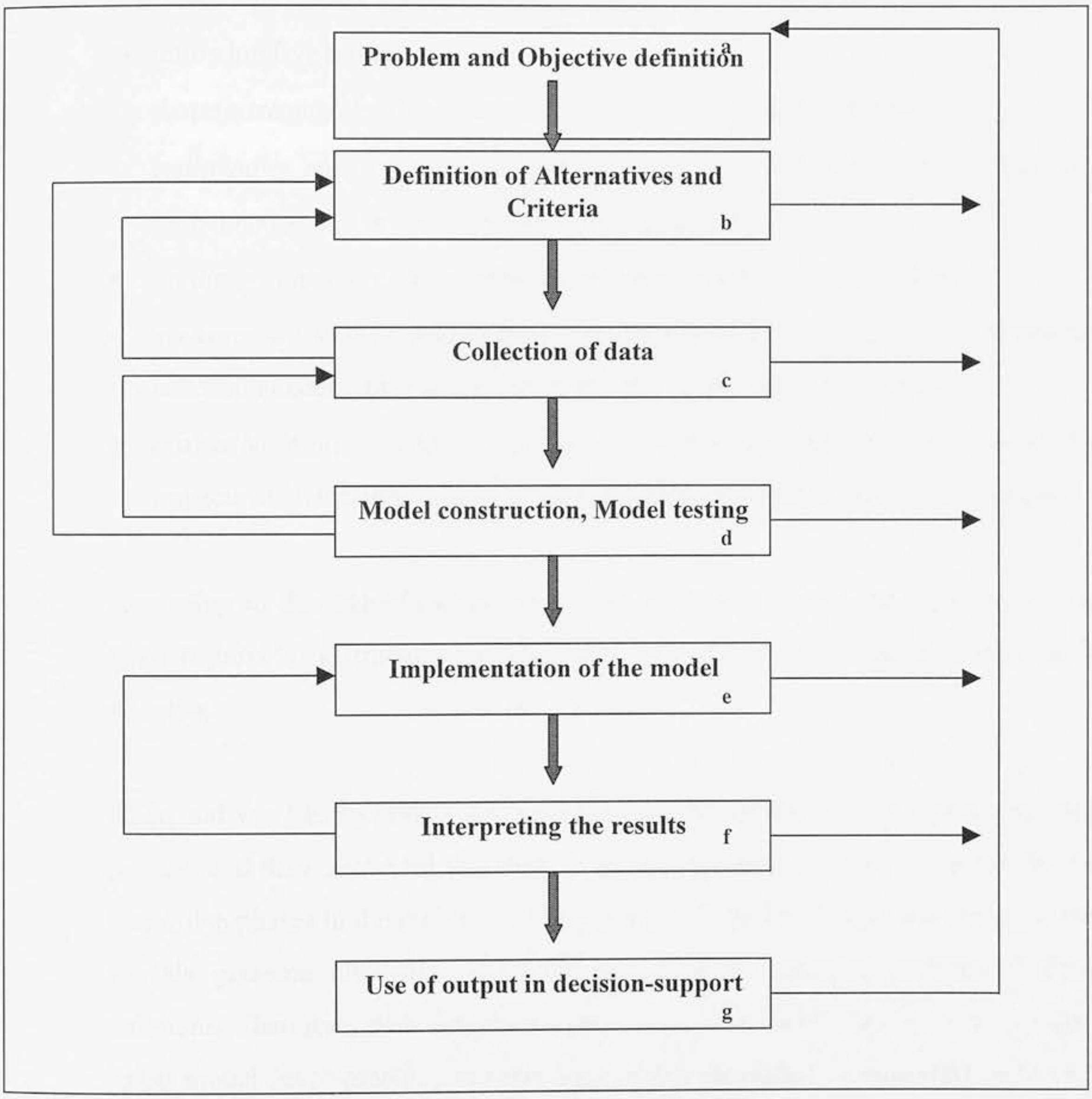
> *"a model is a formal expression of the essential elements of a problem in either physical or mathematical terms".*

France and Thornley (1984) and Braat and van Lierop, (1987) defined a model *"as a simplified version of a part of reality*". The degree of simplification should be appropriate to the objectives, otherwise it becomes its greatest drawback. When building a model, the modeller must consider the need to make other people accept the chosen simplifications and aggregations and to make it possible for them

[11] The model developed simulate the apple industry of Greece, France, Italy, Spain and Germany as will be explained in Chapter 4.

interpret the predictions (Braat and van Lierop, 1987). For this reason, it is important to set up the steps and concepts in the selection and design of the model. As mentioned in chapter 2, formulating a GP model is a process, made up of different steps.

Figure 3.1 Stages in mathematical model construction



Source: Adapted from Dent and Blackie, 1979; Dent *et al.*, 1986; Nijkamp *et al.*, 1990.

There are always many choice possibilities during this process and as a consequence, many studies describe the construction and use of mathematical model as an iterative process (Dent *et al.*, 1986; Nijkamp *et al.*, 1990; Williams, 1993). Figure 3.1 sets out the basic steps of the modelling process and the major linkages between the stages.

3.2.2 Types of models

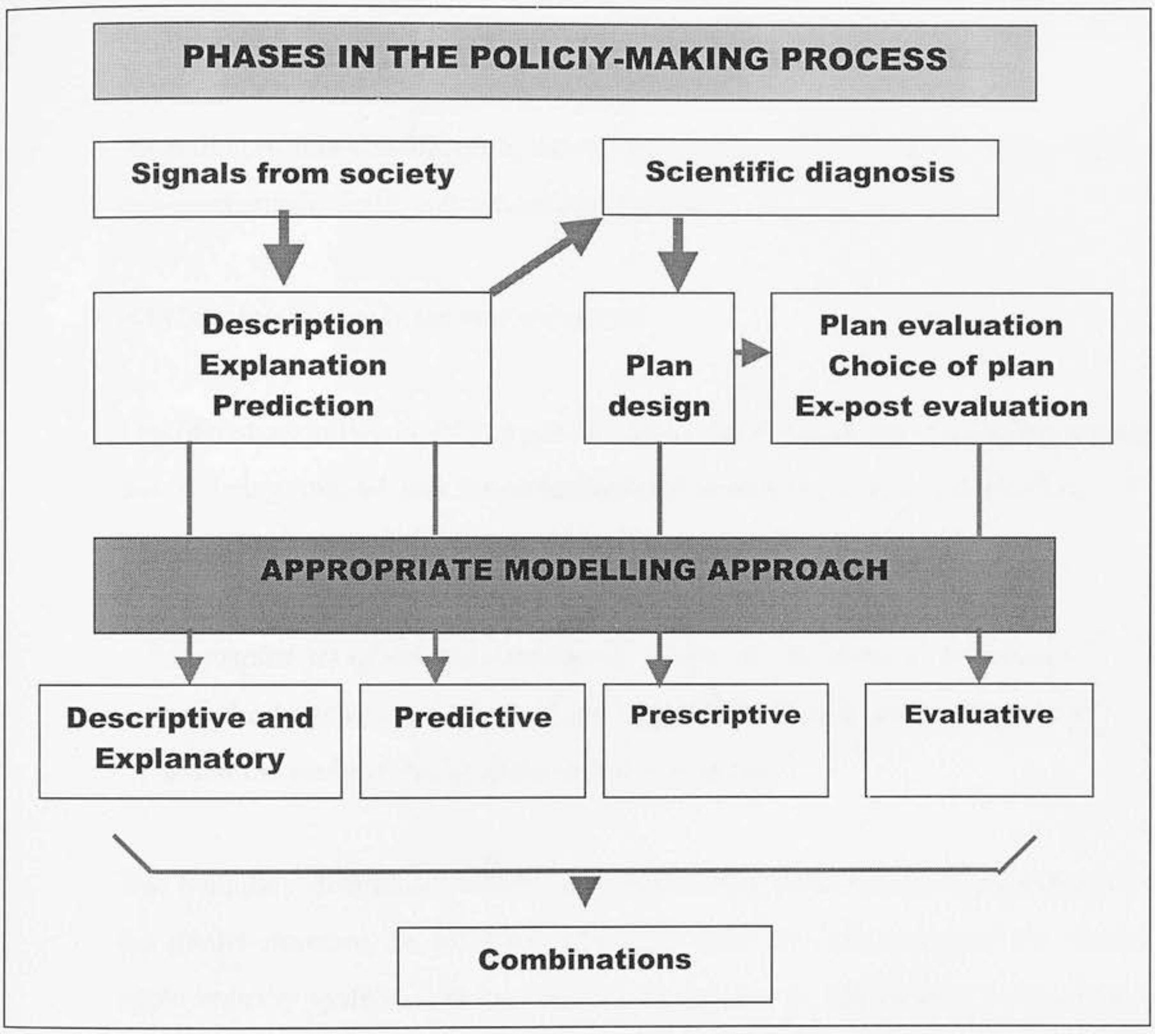
Braat and van Lierop (1987) classified models by their intended use and identified the following five types:

- *descriptive models* which provide a basis for more careful research;
- *explanatory models*, developed on the basis of observation of both input and output and aimed at clarifying the working systems;
- *predictive models*, used to extrapolate developments or forecast changes;
- *management models*, designed to optimise objective functions and to define the condition under which it is possible to achieve the policy objectives;
- *evaluative models*, which provide a structure and algorithm to present the impacts of alternative choices according to selected sets of criteria and weights.

According to this classification, the model developed in this thesis is evaluative, since it provides a structure and algorithm for exploring the impacts of new apple varieties.

Braat and van Lierop (1987) also established different phases in the policy-making process and they suggested that there is an appropriate modelling approach for the respective phases in the problem solving process. In policy design and management, models generate alternative solutions and evaluate potential impacts of these solutions. Therefore, both descriptive and explanatory models are necessary stages in the model development. After that stage, either simulation or optimisation models search for feasible solutions. Thus, the modelling process involves a combination of the different kind of model approaches. This is shown in Figure 3.2.

Figure 3.2 Relationship between policy issue and modelling technique



Source: Adapted from Braat and van Lierop, (1987)

France and Thornley (1984) distinguished six types of models according to its working mode. They divided into three categories of models, namely;

- *empirical and mechanistic:* an empirical model sets out principally to describe. Unlike the empirical model, the mechanistic models attempts to give a description with understanding.
- *static and dynamic:* a static model is defined as a model that does not have time as a variable, whereas a dynamic model does.

- *deterministic and stochastic:* a deterministic model is one that makes definite predictions for quantities, without any associated probability distribution, whereas a stochastic model contains probability distributions within the model.

According to this classification, the model developed in this thesis can be classified as a mechanistic, static and deterministic model.

3.3 Defining the problem and objectives

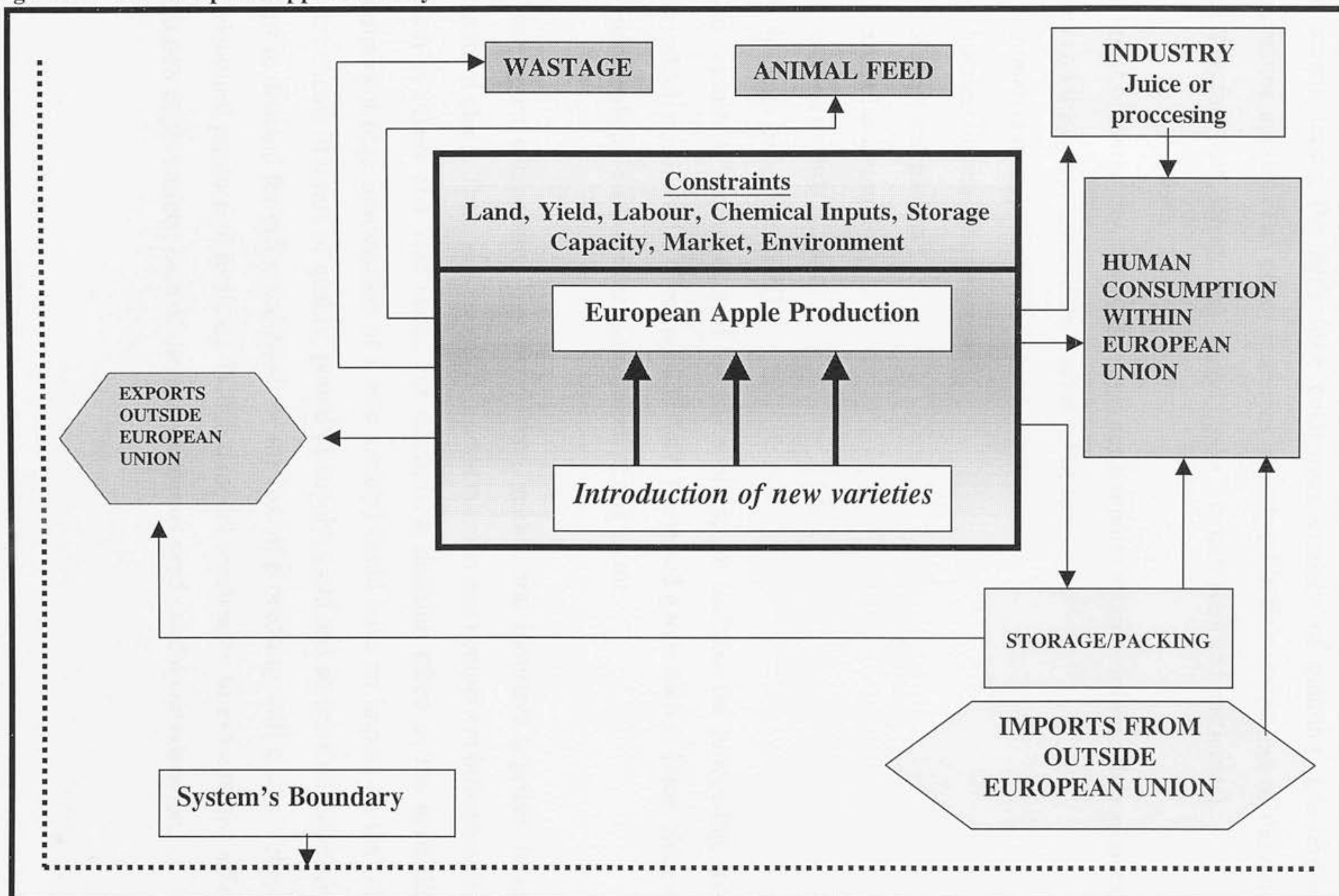
The first steps in the modelling process consist of defining the system, the boundary that is being studied and the objectives for modelling (Dent and Blackie, 1979). These authors defined the system as:

> "*a complex set of related components within an autonomous framework*" and the boundary was defined as " *a contrived component designed to assist the understanding of the system's function*".

The boundary determines which subsystems must be explicitly represented within the model-structure. In order to understand fully the functioning of the European apple industry system, it is therefore first necessary to appreciate its organisational structure. The apple industry is complex because it consists of several sub-components that are co-dependant in many different ways. Figure 3.3 shows the system's components as part of a logistical chain and the system's boundary. The boundary of the EU apple industry is, in physical terms defined by the supply and demand of apples in the geographical region of the 12 member states[12] of the EU.

[12] France, Italy, Portugal, Spain, The Netherlands, United Kingdom, Belgium, Luxembourg, Ireland, Germany, Greece and Denmark (The EU as at 1994).

Figure 3.3 The European Apple Industry



For the EU apple industry there are three important components to stress; a) agriculture; b) market; and c) industry.

In simple terms, the agriculture component consists of planting, growing and harvesting apples. The major resources considered in this component of the model are therefore land, labour, capital and inputs (i.e. fertilisers and pesticides).

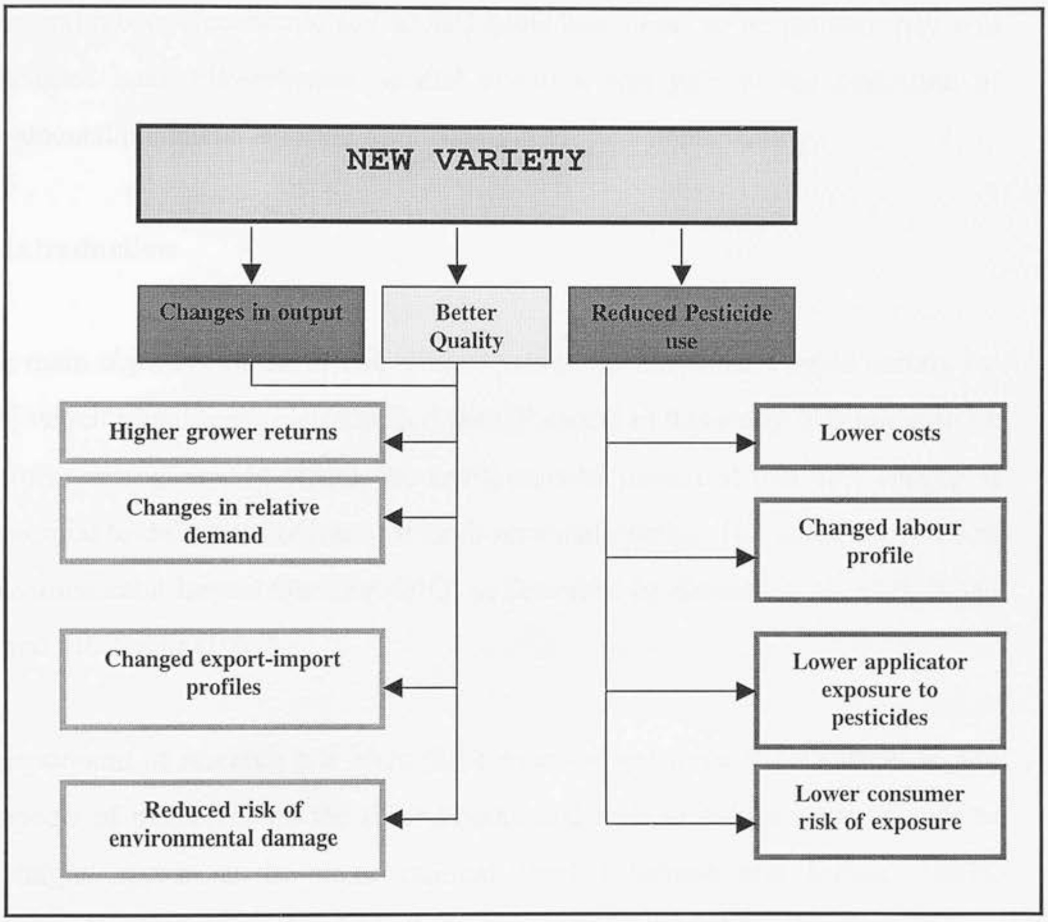
In terms of market requirements, apple consumption is fairly uniform throughout the year and the components of the market relate to:

a) human consumption fresh;
b) human consumption processed;
c) storage and packing;
d) animal consumption;
e) exports outside EU and;
f) imports from outside EU.

The "industrial" component of the EU apple sector includes the processing sector into which raw material (fresh apples) flow. Processed goods such as juice, cider and tinned apple products are the main output of this sector.

These three components (i.e. agriculture, market and industry) together form a logistical chain. Thus, actions and decisions taken in one component influence those taken in others and vice versa. For example, a decision taken in the agriculture component (e.g. introduction of a new variety) could have an impact on the other components in terms of quality, period of supply, yield and so on. Consequently, a shift in demand for processed goods or the cost of processing, will create a shift in agricultural production methods. Within a model constructed to examine the effects of a new apple variety, each of these three sectors need careful consideration.

Figure 3.4 The implications of the introduction of disease resistant varieties for the environment, society and regional and national economics



In addition, since each of these sectors can impact on the environmental consequences of apple production, the social consequences of shifting labour use and the economic consequences of apple production itself, the GP model constructed needed to be capable of incorporating environmental, social and economic parameters and objectives (see Figure 3.4). The following sections explain how this was done.

3.4 Including environmental parameters in the GP model

Income and labour (economic and social) goals being easy to define and they will be discussed later. Nevertheless, special attention was paid to the definition of environmental parameter selected for evaluating the new apple variety.

3.4.1 Introduction

As the main objective of the DEAC project was to develop a new apple variety for the EU which was disease resistant, and the GP model in this study was going to be used for assessing, among others, the environmental impact of this new variety, it was essential to define an indicator of environmental quality. The index chosen was the Environmental Impact Quotient (EIQ) as described by Kovach *et al.*, (1992) and Quin and McGregor (1995).

A large amount of research has taken place over the last three to four decades into the impacts of pesticides on the environment, and how to reduce pesticide use to what might appear to be more rational level (Shahane and Inman, 1987). Methodologies to reduce the dependence on pesticides perhaps began, or were certainly popularised, with Stern *et al.*, (1959) in their model of economic injury levels and the "integrated control concept". Stern addressed the issues of the use of biological control, monitoring, and the economic injury level[13], to attempt to move away from a prophylactic pattern of pesticide use to a more conservative management regime. The use of models such as Stern's have been the foundation of subsequent Integrated Pest Management (IPM) philosophy, and whilst the motivation for the development of such models was initially an economic one, there

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[13] The economic injury level is defined as the lowest (pest) population that will cause economic damage, and therefore represents the point at which control measures should be implemented (Stern *et al.*, 1959).

are potentially considerable environmental benefits to be gained from the use of economic injury levels.

Economic injury level is likely to vary between farms, regions, crops and management strategies, therefore the results of an analysis are not readily transferable. The problem with this and other methodologies using economic injury levels is that a huge amount of data is required at an individual farm level.

Integrated Pest Management (IPM) is a pest management strategy that uses a variety of methods to manage pests. By definition, IPM is the technique of controlling pests, be they diseases or insects, using a combination of methods (thresholds, forecast, monitoring, biological agents and so on), without solely relying on chemical pesticides, to produce a safe, economic crop (Olkowski *et al.*, 1991; Shecnk and Wertheim, 1992, McDonald and Glynn, 1994). Chemical controls are used if no other suitable method is available, but in the past pesticide choice decisions have been based on the efficacy and cost of the compound rather than on environmental hazard (Kovach *et al.*, 1992). It was this situation, and the assumptions made by some experts that if the compound had been approved by Government it must be safe, that prompted the development of the Environmental Impact Quotient (EIQ) model of pesticide impact.

The EIQ model was developed to compare different pesticides and different pest management practices to ultimately determine which programme was likely to have the lowest environmental impact. Extensive data was used to construct the model from a variety of scientific and regulatory sources, such as the Environmental Protection Agencies (EPA) pesticide registration process and the Extension Toxicology Network (EXTONET)[14], a collaborative toxicology and pesticide education project involving Cornell, Michigan State, Oregon and California Universities (Kovach *et al.*,1992).

[14] Many more sources of pesticide impact data were used in order to consider as many impacts as possible.

The primary module of the EIQ model is an algebraic equation that generates a composite index of environmental impact for each pesticide analysed (Levitan *et al.*, 1995). A second equation, "the Field Use Rating[15]"(FUR), allows for a site specific analysis based on the active ingredient of the pesticide and total dosage. This then allows for the achievement of the main objective of the model; the comparison between different pest management strategies in terms of environmental hazard or impact.

The EIQ model addresses the issues of hazard created by the application of pesticides to farm-workers, consumers and non-target flora and fauna. To simplify the interpretation of the data the toxicity of the active ingredient of each pesticide was grouped into low, medium or high toxicity categories, and rated on a scale from 1 to 5 (1 being very low impact, 3 being a medium impact and 5 being very high impact). According to Kovach et al., (1992), a value is assigned to each category of potential impact: the rating. An additional weight (weighting criteria) is also assigned to each of the sub-categories farm-worker, consumer and ecological impact, again based on a 1 to 5 scale. Although weighting requires value judgements, as long as they are not prejudicial or illogical, and represent the opinions of both experts and stakeholders (scientists, farmers, consumers and policy makers) then a number of different weighting systems might satisfy the requirements of environmental impact models (Levitan, 1997). The Kovach *et al.,* (1992) model has both weighted and rated variables. The weighting criteria is based on a subjective assessment of the relative importance of various environmnetal categories, such as effects on applicators, groundwater effects and so on (see Table 3.1), whereas the rating is based on the toxicity of the compound (Table 3.2).

[15] The EIQ field use rating is simply EIQ value X % active ingredient X Rate of use.

Table 3.1 Weighting factors of the EIQ equation .

	Weight	Effects	Max. Score	Weighted Variables	Symbol	Rating
Farmworker Component	5	On Applicators	125	Chronic toxicity	C	1,3, 5
				Acute dermal toxicity (LD_{50} for rabbits/rats)	DT	1,3, 5
	1	On Pickers	25	Acute dermal toxicity (LD_{50} for rabbits/rats)	DT	1,3, 5
				Plant surface half-life	P	1,3, 5
				Chronic toxicity	C	1,3, 5
Consumer Component	1	Consumers (food residues)	75	Soil half-life*	S	1,3, 5
				Plant surface half-life*	P	1,3, 5
				Systemicity (ability to be absorbed by plants)	SY	1,3, 5
	1	On Ground-water	5	Leaching potential (water half-life, solubility, adsorption coefficient, soil properties)	L	1,3, 5
Ecological Component	1	On Aquatic Organisms	25	Fish toxicity (96 hr LC_{50})	F	1,3, 5
				Surface loss potential (water half-life, solubility, adsorption coefficient, soil properties)	R	1,3, 5
	3	On Birds	75	Bird toxicity (8 day LC_{50})	D	1,3, 5
				Soil half-life*	S	1,3, 5
				Plant surface half-life*	P	1,3, 5
	3	On Bees	75	Bee toxicity	Z	1,3, 5
				Plant surface half-life	P	1,3, 5
	5	On Beneficials	125	Beneficial arthropod toxicity	B	1,3, 5
				Plant surface half-life	P	1,3, 5

Source: Adapted from Levitan, 1997.

Table 3.2 Rating criteria of the EIQ equation (adapted from Levitan, 1997).

Variable	Symbol	Rating Scores & Criteria		
		1	3	5
Chronic toxicity[16]	C	little or none	possible	definite
Acute dermal toxicity (LD_{50} for rabbits/rats mg kg^{-1})	DT	>2000	200-2000	0-200
Bird toxicity (8 day LC_{50})	D	>1000 ppm	100-1000 ppm	1-100 ppm
Lethality to honey bees (at field doses)	Z	relatively non toxic	moderately toxic	highly toxic
Beneficial arthropod toxicity	B	low impact	moderate impact or post-emergent herbicides	severe impact
Fish toxicity (96 hr LC_{50})	F	>10 ppm	1-10 ppm	< 1 ppm
Soil residue half-life	S	<30 days	30-100 days	>100 days
Plant surface residue half-life	P	1-2 weeks	2-4 weeks	>4 weeks
Mode of Action (Systemicity)	SY	non-systemic and all herbicides	systemic	
Leaching potential (water half-life, solubility, adsorption coefficient, soil properties)	L	small	medium	large
Surface loss potential (water half-life, solubility, adsorption coefficient, soil properties)	R	small	medium	large

Source: Adapted from Levitan, 1997.

The EIQ rating is described as an overall function of the following variables:

Dermal Toxicity - DT

Chronic Toxicity - C

Systemicity - SY

Fish Toxicity - F

Leaching Potential - L

Surface Loss Potential - R

Bird Toxicity - D

---

16 Long term health impacts, calculated as the average of ratings from laboratory tests on small mammals designed to assess reproductive, teratogenic (causing deformities in

Soil Half Life - S

Bee Toxicity - Z

Beneficial Arthropod Toxicity - B

Plant Surface Half Life - P

The EIQ for each sub-component is given by:

EIQ *farm-worker* = C x (DT x 5) + (DT x P) (3.1)

EIQ *consumer* = C x ((S + P) / 2) x SY + L (3.2)

EIQ *ecological* = (F x R) + (D x ((S + P) / 2) x 3 + (Z x P x 3) + (B x P x 5) (3.3)

The final EIQ equation is equal to the average of the farm-worker, consumer and ecological component. Farm worker risk, for example, is defined by the sum of applicator exposure, plus picker exposure times the long term health effect or chronic toxicity. The total EIQ value for each pesticide is the sum of the three sub-components, and is represented by a single figure. As examples, the fungicide *fosetyl-Al* (Aliette) has a low impact value of 13.7, as has the insecticide *hexakis* (Vendex) at 12.8. A medium impact is the insecticide *mevinphos* (Phosdrin) at 28.2, whilst *methidathion* (Supracide) has a high impact at 69.3.

The strengths of the approach are the range of impacts considered in the analysis, the ease of use of the final model for farmers, and the ease of understanding for policy makers. An example of the model of Kovach *et al.*, is presented in Table 3.3.

Table 3.3 The EIQ field use rating (EIQ FUR) of three insecticides.

Compound	EIQ	A.I. (*)	Rate	EIQ FUR
Sevin 50WP (Carbaryl)	22.60	0.50	6.00	**67.80**
Thiodan 50WP (Endosulfan)	40.50	0.50	3.00	**60.80**
Guthion (azinphos-methyl)	43.10	0.35	2.20	**33.20**

(*) Active Ingredient

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offspring), mutagenic (affecting genes and chromosomes), and oncogenic (tumour growth) effects.

Source: Adapted from Kovach *et al.*, 1992.

However, assigning a single environmental impact figure for pesticides may well be misleading unless spatial aspects are considered. For instance, the likelihood of a farmer "polluting" the environment will be far greater if a) he is situated on soils with a high leaching potential, and b) he is situated within a few metres of a river or lake. These two factors could well be added to the EIQ equation without too much difficulty. This would allow farmers to assess the environmental impact of their pest management strategy based not only on the relative toxicity of the pesticides they use, but also on the geographical conditions in which they farm. In addition to this, climatic conditions will also have an impact on the amount of pesticides polluting the environment. Pesticides applied prior to or during heavy rainfall are much more likely to find their way into watercourses for example (Eke *et al.*, 1996). Also temperature, rainfall and humidity will all have an influence on the number of different pests and diseases affecting production, as well as on the incidence of pest attack. A critical factor is also the method used to report this data. Dushoff *et al.*, (1994) have criticised the method of reporting results from the EIQ model as being misleading.

The purpose of the model presented by Kovach *et al.*, (1992) is to provide farmers with greater information on environmental impact (or potential impact) in order that they can make comparisons between different chemical compounds, and between different management strategies (Kovach *et al.*, 1992; The Pesticide Trust, 1993). As we can see in Table 3.3 it is possible to map the differences, in terms of potential impact, between different compounds, thus allowing the farmer to choose the least environmentally harmful pesticide option[17]. It may well be that we wish to assign a target EIQ, or threshold, above which represents unacceptable pesticide use levels. For the GP model, an arbitrary target was assigned. It will be explained in more detail later in this chapter.

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[17] The model of Kovach *et al.*, (1992), however, makes no judgement as to what level of pesticide use is acceptable or unacceptable.

To account for different active ingredient percentages, different frequencies of application and different application patterns Kovach *et al.*, (1992) developed a simple equation: the EIQ Field Use Rating (FUR). The rating is achieved by multiplying the EIQ value of the pesticide, by the percentages of active ingredient, and by the quantity applied per hectare (kg/ha) to give:

$$\text{EIQ } FUR = \text{EIQ x \% a.i. x Rate} \tag{3.4}$$

Thus, a total figure for hazard can be assigned to each orchard, or management strategy by summing the EIQ values for each compound used as part of that strategy.

There were a number of reasons why the EIQ approach of Kovach *et al.*, (1992) was chosen to represent environmental impact in the GP model for this study, but the main criteria of choice can be summarised as follows:

- The EIQ model is a decisional aid and so has the same philosophical aims and objectives as the GP model.

- The EIQ is easy to use and to understand. Ease of use and more importantly ease of understanding, are a vital characteristic of both the EIQ model and modelling in general. If the end users of the model are unable to interpret results then the model is, to all intents and purposes, useless.

- It is applicable across all geographical locations. All that is needed to fulfil the data demands of the EIQ model are pesticide use patterns (quantities used), and the type of pesticide used. Thus, comparisons can be made across regions.

- The purpose of this analysis is to make comparisons (in terms of environmental impact) between regions, and assess the effect on environmental impact levels the introduction of disease resistant varieties (and hence different management strategies) might have.

- It reduces environmental impact to a single figure. Because of GP model is essentially an economic model, two options in the incorporation of environmental impact coefficients in the model were available. Firstly, environmental impact could be transformed into an economic value, or secondly, a compatible numeric value could be used that need not be an economic value. Thus, the EIQ model reduces environmental impact to a single figure for ease of comprehension, but that figure is also compatible with the other goals of the model.

- Unlike other pesticide impact models, such as that of Penrose *et al.*, (1994), the EIQ model does not seek to trade-off environment against economics. This is potentially a serious flaw in Penrose *et al.*, (1994) model as it allows farmers to choose pesticides on the basis of efficacy and cost above environmental impact.
- The EIQ model merely describes potential impact objectively, without indicating what level of pesticide use is either optimal or acceptable. It is up to the decision-maker, the end user of the model, to decide what level of pesticide use is acceptable to society as a whole. This is a great strength of the EIQ approach.

3.4.2 EIQ values used in the model

The EIQ values of Kovach *et al.*, were combined with observable pesticide use patterns in each Member State, to form the EIQ FUR (environmental impact) for each region. Table 3.4 presents the EIQ values for both existing and the new variety for each EU country. At the same time, the table indicates the EIQ values by type of pesticide (fungicide, insecticide and herbicide) and by EIQ component (field-worker, consumer and environment). As mentioned, this table also shows the EIQ values for the new variety. The data used for the new apple variety can be used for illustrative purposes only, since no data were available regarding the likely pesticide use characteristics of the new variety. This was strictly unobservable since the new variety was still under test, by definition, under the DEAC project. Therefore, hypothetical values had to be assumed, which would later be tested for sensitivity (see Chapters 5 and 6).

The EIQ FUR values presented in Table 3.4 were obtained by applying the formula 3.4. The EIQ values for each active ingredient and compound are shown in Appendix 3.3. The use rate for each compound by country and by region comes from the information received from the different EU institutions in the DEAC project having used average values.

Table 3.4 EIQ values for existing and new varieties for selected apple growing regions of Europe.

Country/Pesticide	EVPFUR	NVPFUR	EVCFUR	NVCFUR	EVEFUR	NVEFUR	Total EIQ EV	Total EIQ NV
Greece								
Fungicide	883.04	335.5	294.7	112	1468	557.8	2645.74	1005.3
Insecticide	212.1	212.1	34.3	34.3	576.2	576.2	822.6	822.6
Herbicide	20.5	20.5	9	9	95.1	95.1	124.6	124.6
Totals	1115.6	568.1	338	155.3	2139.3	1229.1	3592.94	1952.5
Belg/Lux								
Fungicide	475.6	237.8	143.9	71.95	896.4	448.2	1515.9	757.95
Insecticide	14.4	14.4	10.6	10.6	115.5	115.5	140.5	140.5
Herbicide	44	44	23.05	23.05	175.4	175.4	242.45	242.45
Totals	534	296.2	177.55	105.6	1187.3	739.1	1898.85	1140.9
Italy								
Fungicide	1609.8	402.45	692.3	173.1	5534	1383.5	7836.1	1959.05
Insecticide	703.3	703.3	111.2	111.2	1610	1610	2424.5	2424.5
Herbicide	0	0	0	0	0	0	0	0
Totals	2313.1	1105.8	803.5	284.3	7144	2993.5	10260.6	4383.55
France								
Fungicide	4178	2089	888	444	9590	4795.2	14656	7328.23
Insecticide	358.4	358.4	31	31	621.9	621.9	1011.3	1011.3
Herbicide	133.4	133.4	40.6	40.6	187.1	187.1	361.1	361.1
Totals	4669.8	2580.8	959.6	515.6	10399	5604.2	16028.4	8700.63
Spain								
Fungicide	780.15	585.1	366.4	274.8	5030	3772.8	6176.55	4632.7
Insecticide	202.2	202.2	36.6	36.6	505.6	505.6	744.4	744.4
Herbicide	26.6	26.6	14.3	14.3	102.9	102.9	143.8	143.8
Totals	1009	813.9	417.3	325.7	5638.5	4381.3	7064.75	5520.9
UK/Eire								
Fungicide	293.6	73.4	108.2	27.05	622.5	155.6	1024.3	256.05
Insecticide	114	114	24.54	24.54	367.2	367.2	505.74	505.74
Herbicide	67.9	67.9	41.75	41.75	185.9	185.9	295.55	295.55
Totals	475.5	255.3	174.49	93.34	1175.6	708.7	1825.59	1057.34
Portugal								
Fungicide	460	115	209.2	52.3	1667	416.7	2336.2	584
Insecticide	2403.6	2403.6	161.5	161.5	3189	3189	5754.1	5754.1
Herbicide	0	0	0	0	0	0	0	0
Totals	2863.6	2518.6	370.7	213.8	4856	3605.7	8090.3	6338.1
Netherlands								
Fungicide	363.1	181.55	112.6	56.3	400.9	200.45	876.6	438.3
Insecticide	129.1	129.1	60.77	60.77	316.8	316.8	506.67	506.67
Herbicide	90.4	90.4	61.7	61.7	359.4	359.4	511.5	511.5
Totals	582.6	401.05	235.07	178.77	1077.1	876.65	1894.77	1456.47
Germany								
Fungicide	195.6	97.8	114.5	57.25	646.4	323.2	956.5	478.25
Insecticide	29.3	29.3	8	8	8	8	45.3	45.3
Herbicide	10.6	10.6	2.6	2.6	2.6	2.6	15.8	15.8
Totals	235.5	137.7	125.1	67.85	657	333.8	1017.6	539.35
Denmark								
Fungicide	195.6	150	114.5	99.8	646.4	545	956.5	794.8
Insecticide	29.3	29.3	8	8	99.5	99.5	136.8	136.8
Herbicide	10.6	10.6	2.6	2.6	49.1	49.1	62.3	62.3
Totals	235.5	189.9	125.1	110.4	795	693.6	1155.6	993.9

PFUR = *Field-worker* Field Use Rating, **CFUR** = *Consumer* Field Use Rating, and **EFUR** = *Environment* Field Use Rating. The prefixes **EV** and **NV** represents the new variety and existing varieties field use rating for each of the components, respectively.

Source:Adapted from Kovach *et al.*, 1992 and EU institutions (see page 75)

3.5 Risk and Uncertainty

Agricultural systems are characterised by the complexity and interdependency of their componentets and by the variability and risk involved in their management (Berbel, 1993). As an example, forest managers often have to deal with insufficient or imperfect information due to the inherent complexity of the system (Mendoza *et al.*, 1993). Incomes vary from year to year primarily because of variable weather conditions, disease and pests and changes in prices and other market conditions. Therefore, in any given year the gross margin of an activity is unlikely to coincide exactly with the expected value.

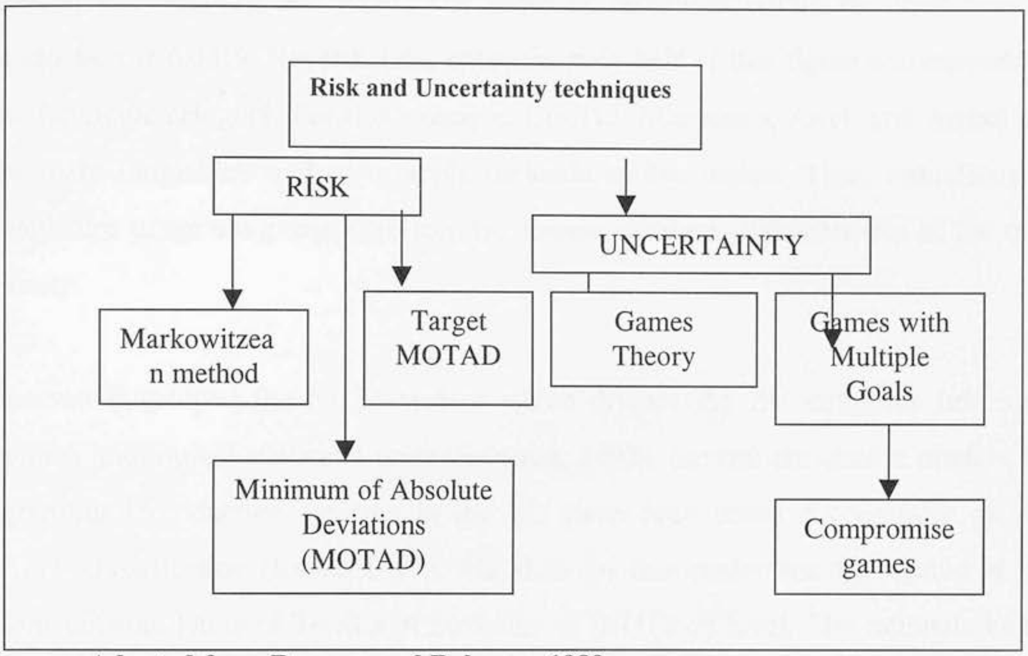
According to Romero and Rehman (1989) risk and uncertainty can be treated as particular cases of the MCDM paradigm having theoretical and practical advantages. These authors also show that traditional risk and uncertainty analysis is by its nature multiobjective analysis with two objectives of profits and a measure of their variability.

Kruseman *et al.,* (1997) define uncertainty as "*imperfect knowledge*" and risk as "*uncertainty of consequences*".

Different methods of dealing with risk and uncertainty in farm planning models can be incorporated within a multiple criteria framework (Romero and Rehman,1985). In addition, generally models dealing with uncertainty are of game theoretic type while those including risk are based on mathematical programming techniques. This is illustrated in Figure 3.5

This study does not include risk and uncertainty analysis as it was defined above. Nevertheless, a comprehensive sensitivity analysis is developed in Chapter 6 in order to counteract this shortcoming.

Figure 3.5 Techniques for dealing with risk and uncertainty in agricultural planning



Source: Adapted from Romero and Rehman, 1989.

3.6 Data Collection

The scope of the model has been limited to a production year. The base year adopted for this model was 1994, and all data used relate to this year. Since the primary purpose of this study is to analyse the impacts of reduced pesticide use in the apple sector, a special aggregation procedure is used for the apple orchard activities. Data was collected from each of the Member States regarding pesticide use patterns, highlighting quantities used, type of pesticide and the internal costs associated with pesticide use. In addition to this, information about apple prices and market demand was collected. Table 3.5 presents all the sources of information used in this study, for each country.

An extensive survey was also carried out to look at the total costs of production on apple orchards throughout the EU . An example of the data obtained for each region is presented in Table 3.6. This table refers to an average cost of apple (per hectare) production for all apple varieties grown in a particular region of Italy. Emilia Romagna (NUTS-2) is one of the more productive Italian regions. Costs were divided into variable and fixed. The share of pesticides within the total cost of production is 6.34%. Nevertheless, approximately half of this figure corresponds to the fungicide category. For this example, CuCl12, Mancozeb, Anvil and Saprol are the main fungicides applied to apple orchards in this region. Thus, reductions in fungicides usage are going to reflect the disease resistant characteristics of the new variety.

Eurostat developed the NUTS-system which divides the EU countries into well defined and logical statistical units (Eurostat, 1992). Several simulation models for agricultural production systems in the EU have been based successfully on the NUTS-classification (Renia, 1997). The data for this study was aggregated at the Nomenclature Units of Territorial Statistics -2 (NUTS-2) level. The rationale being that more detailed information was not available, the conditions within NUTS regions, in terms of climate, vegetation, soil and water availability, are assessed to be homogeneous resulting in uniform productive processes and costs and finally, for an assessment of the impacts of the new apple variety, it appears sufficient to subdivide only up to the NUTS-2 level The NUTS-classification systems consists of 183 regions at NUTS-2 level for the twelve EU countries (Eurostat, 1992).

Table 3.5 Goal programming model data source.

Country	Region	Data Source
United Kingdom	South-east	ADAS (1995), English Apples and Pears (1995), ENFRU (1995)
France	Tarne and Garonne	Centre de Economie Rurale de Tarn-Garonne (1996). CEMEGREF (1995)
Italy	Emilia Romagna	Confcooperative, Ferrara, (1995, 1996). Personal visits to Italian orchards (1996).
Netherlands	Country	Landell Mills (1996)
Germany	South	Dr. Bernard Sessler, University of Hochenheim, unpublished report (1996)
Belgium	Country	Dr. Peter Jaeker, orchard accounts (unpublished) (1995).
Luxembourg	N/A	No data, taken to be same as Belgium.
Eire	N/A	No data, taken to be same as UK.
Denmark	N/A	No data, taken to be same as Germany.
Greece	North	University Thesalonika/SAC survey (unpublished) (1996).
Spain	Cataluña	Lerida, La Almunia de Doña Godina and Costa Brava apple co-operatives, personal visit (1996)
Portugal	Central	Personal communication on visits to local co-operatives (1996). Ministry of Agriculture (1995)

Table 3.6 Apple production costs in ECU for Emilia Romagna, Italy, 1994.

Variable Costs	Quantity (Kg/ha)	ECU (Per unit)	ECU (per Ha)	% of Total
Azote (nitrate)	70	0.4	28.3	
Phosphorous	30	0.35	10.4	
Total Fertilisers	**100**		**38.7**	**0.33**
CuC12, 50%	10	2.72	27.2	
Mancozeb	48	4.45	213.5	
Anvil	1.4	23.11	32.4	
Metidathion	5	10.23	51.1	
Azinphos Metil	16	6.82	109.1	
Metasistox	3	21.37	64.1	
Nomolt	0.6	118.43	71.1	
Saprol	8	19.25	154	
Carbaril	2.5	4.85	12.1	
Total Pesticides	**94.5**		**734.5**	**6.34**
Labour (Hours)				
Irrigation	20	9.54	190.8	
Thinning	1.5	29.15	43.7	
Soil treatment	25.5	27.57	703.1	
Fertiliser application	2	25.77	51.5	
Pesticide application	34.5	29.15	1005.7	
Harvesting	265	9.92	2627.7	
Pruning	153	10.37	1586.7	
Total Labour	**501**	**12.39**	**6209.2**	**53.6**
Fixed Costs				
Irrigation			291.8	
Harvesting			238.5	
Pruning			386.9	
Taxes			978	
Land Rent			397.5	
Management (1)			265	
Insurance			492.9	
Depreciation(2)			1382.8	
Others(3)			169.6	
Total Fixed Cost			**4603**	**39.73**
TOTAL COSTS			**11585.4**	**100**

(1)Expenditures for the control and making decisions on the apple orchard.

(2) This item includes depreciation of the apple orchard and depreciation of buildings and associated equipment.

(3)Other costs not included in the list.

Table 3.7 shows the cost and type of pesticide, and quantities used per hectare per country and region. The total value represents a weighted average for each active ingredient. Each country and region have different pesticide usage patterns in terms of both, the amount of pesticides and percentage of active ingredient. A weighted average allows us to have a representative figure of the value and amount of pesticide used in each area. This value will be used for running the GP model. For instance, Italy has a weighted average fungicide usage of 44.99 kg/ha and a weighted value of 9.49 ECU per kilo. Thus, the total value of fungicide per hectare for Italy is:

44.99 kg of fungicide x 9.49 ECU = 426.95 ECU/hectare

The same methodology was followed for each EU country, for each NUTS 2 region and for each variety (see Appendix 3.1).

Table 3.7 Pesticides usage and values: ***weighted averages.***

Active Ingredient	Kg/ha (1)	%AI (2)	KgAI/ha (3)	% (4)	ECU/kg (5)	ECU/AI (6)	ECU/kg Pesticide (4*6)
Fungicides							
Copper Oxy.	10,00	0,50	5,00	11,11	2,71	5,42	0,60
Mancozeb	48,00	0,80	38,40	85,35	4,45	5,56	4,75
Hexaconazole	1,40	0,05	0,07	0,16	23,11	462,20	0,72
Triforinel	8,00	0,19	1,52	3,38	19,25	101,32	3,42
Total			**44,99**				**9,49**
Insecticides							
Oxidemeton	3,00	0,25	0,75	4,53	21,37	85,48	3,88
Teflubenzuron	0,60	0,15	0,09	0,54	118,43	789,53	4,30
Methidathion	5,00	0,42	2,10	12,70	10,22	24,33	3,09
Azinphos-M	16,00	0,85	13,60	82,22	6,50	7,65	6,29
Total			**16,54**				**17,55**
Others							
Carbaryl	2,50	0,45	1,13	100,00	4,85	10,78	10,78
Total			**1,13**				**10,78**

COUNTRY: ITALY NUTS-2 Emilia Romagna VARIETY: ***All***

Data regarding costs of production and pesticide use form the basis of the GP model which predicts the impacts of the introduction of new apple genetic stock into European horticultural production.

For the purposes of this thesis, apple-producing regions were identified where data allowed for an assessment of the environmental impacts of pesticide use. One or more regions were selected from each of the Member States. The choice of region was based on both availability of data and amount of apples produced. However, the data collected for this study represents, approximately, seventy percent of the total apple production of each Member State. The regions selected for analysis are indicated in Appendix 3.2. Each country was mapped showing the regions chosen for this study.

Where possible, data obtained was cross-checked by contacting marketing organisations, visiting apple producing regions and talking to research stations in each Member State. The success of this exercise was mixed, with successful communication taking place with Spain, Portugal, Greece and Italy only.

For the purposes of this analysis, one or more representative region was selected from each European Union Members State. The regions chosen for the analysis were those with the most intensive apple production in that country. The data gathered was necessarily aggregated since localised, orchard level data, was impossible to identify without visiting each region.

Data collection was the most serious constraint on the analysis, as data promised by DEAC project participants at the beginning of the project was not forthcoming. The data collection period, therefore, was eighteen months as opposed to the three months originally anticipated. The most difficult task in data collection was in the identification of the most appropriate organisations to contact. Ultimately, however, aggregated data was identified from Agriculture Ministries, universities and marketing organisations and, in the case of Greece, an orchard field survey.

Table 3.8 shows a summary of the data used for feeding the GP model. As was mentioned above, it was not possible to get all the information. So, some figures included in the model are based on estimated information. For example, the rate of losses in storage. In Chapter 6, sensitivity analysis is carried out to test the sensitivity of the model results against some of these estimates and other assumptions which had to be made due to data scarcity.

Table 3.8 Summary of the information included in the model.

Production Aspects	Storage	Market	Environmental
Total area under apple cultivation	Total Capacity	Farm gate price per tonne	EIQ total/ha
Fertiliser/ha Amount and Value (N-P-K)[18]	Rate of apple losses in storage	Domestic demand	EIQ Field-workers/ha
Fungicide/ha Amount and value	Cost of storage per tonne and month	Imports and value	EIQ Consumers/ha
Insecticide/ha Amount and value		Exports and value	EIQ Environment/ha
Other pesticides/ha Amount and value		Industry demand and value	
Labour Harvest/ha Amount and value		Wastage	
Labour Pruning/ha Amount and value			
Labour Others/ha Amount and value			
Total cost of production			

[18] Nitrogen, Phosphorous and Potassium

3.7 The Goal Programming (GP) model

The general aim of GP is to satisfy several goals rather than an optimising solution. It is necessary to transform the objective function into equality constraint equations and to set these equations equal to a desired goal level (target). For that, we need to add deviational variables in order to allow for under and over achievement of the target. GP minimises the deviations from the desired targets[19] and what is actually achievable. This is achieved by transforming the objectives into constraint equations, each equation is set equal to desired goal level and through the addition of positive (p_i) and negative (n_i) deviation variables which symbolise over-achievement and under-achievement of each goal, respectively.

As specified in Chapter 2, the minimisation of deviations from predetermined targets can be accomplished by several alternative methods, and of these the three most widely used and best known are lexicographic goal programming (LGP), weighted goal programming (WGP) and the MINMAX GP (Romero, 1991).

Also as identified in Chapter 2, Weighted Goal Programming was applied to this study because it is a useful tool when a decision-maker can not to determine precisely the relative importance of the objectives (Winston, 1995) and wishes to use the model more as tool for sensitivity analysis of different alternatives.

3.7.1 Structure of the Goal Programming Model

Several assumptions made in the design of the model are stated below:

- The model was to be comparative-static, using 1994 as the baseline for the EU apple industry.

[19] Targets are acceptable levels of achievement in the improvement of various attributes under consideration. On combining an attribute with target a goal is established (Romero and Rehman, 1989)

- It was assumed that an average of 0.33% of apple losses occur by volume each month during storage. This value was assumed to be constant throughout the year.
- Maximum numbers of hectares under apple production were those existing in 1994.
- Demand for apples for industrial proposes (processing) was estimated in 15% of the total production in those countries where it was not possible to get reliable information.
- The technical coefficients used to represent the production of apples were given by an average of the prevalent systems of production. However, this assumption could be relaxed by adding new activities with the corresponding technical coefficients.
- Total apple production is assumed to be marketed within the year that it was produced, implying there would be zero net stock at the end of the production period. Therefore, supply and demand was matched representing a competitive market.
- Production coefficients were estimated across both NUTS-2 regions and varieties, where permitted by the availability of data.
- The total domestic consumption per annum was divided by twelve, obtaining domestic consumption per month (i.e. consumption assumed as non-seasonal).
- The model is run with technical coefficients that represent the situation when the orchard reaches the maximum commercial production. Thus, it does not take into account the period (approximately 0 to 5 years) that there is no returns on the initial investment. This can be handled applying an approach based on cost-benefit-analysis (Alston *et al.*, 1995). It is based on the calculation of expenses and incomes that are the result of the new technology. The three most important techniques are; a) Internal Rate of Return; b)Net Present Value and c) Benefit-Cost Ratio.

At first, the model would be run with the existing technical coefficients of the existing apple varieties. Then, a new activity would be added incorporating the technical coefficient of the new (disease resistant) variety. This new activity would then compete against the existing varieties. In order to compare results, it would then be necessary to run different scenarios which would simulate alternative weights attached to the goal targets. In this way, the model would allow simultaneous comparison of social, environmental and economic objectives.

The general structure of the model is shown in Table 3.9 and it is given as:

$$Minimise \sum_{i=1}^{n} (w_i n_i + w_i p_i) / t_i \tag{3.5}$$

subject to

$$f_i(x) + n_i + p_i = t_i \tag{3.6}$$

and

$$x \in F \tag{3.7}$$

Where;

n_i = negative deviational variable measuring the amount of under-attainment of the target

p_i = positive deviational variable measuring the amount of over-attainment of the target

w_i= the relative weights attached to the deviational variables

t_i = target set for the *i-th* attribute

$f_i(x)$ = mathematical expression for the *i*-th attribute

F = is the feasible region

The set of goals represented by *I* relates to the three objectives of social achievement (measured in terms of labour use); environmental impact (measured by the EIQ); and, economic return (measured in terms of net margin per hectare).

The model activities[20] are indicated at the top of the Table 3.9. They were divided into ten different groups. The last two columns account for the deviational variables, one for negative variables and the last one for positive variables.

Activities are grouped as follows:

a) Apple production activities, representing different varieties and different NUTS within each European country. The followings inputs and outputs were considered in apple production activities: fertiliser (Nitrogen, Phosphorous and Potassium), pesticides (Fungicides, Insecticides, Others), labour (Harvest, Pruning, Others) and yield per hectares, by variety and by NUTS.
b) Apple storage activities, representing apple's volume storaged by month.
c) Apples sold at the domestic market, by both, month and variety.
d) Apples imported from outside the European union, by country, by month and by variety.0
e) Apples exported outside the European union, by country, by month and by variety.
f) Apples that are sold for industry purposes by country and by month.
g) Apples which are sold for other uses (e.g. animal feed) by country, by variety and by month.
h) Wastage apples
i) Environmental outputs (EIQ units), by country, by NUTS and by variety.
j) Activities representing pesticides, fertilisers and labour costs

[20] For each constraint and activity, the model was assigned a specific code identified by no more than eight characters. Code identifications can be found in Appendix 3.4

Table 3.9 General Structure of the Goal Programming Model for European Apple Industry

Activities	(a) Production Activities 1,.......n	(b) Storage 1,......m	(c) Sell domestic Market 1,........l	(d) Imports Extra EU 1,.........o	(e) Exports to Extra EU 1,........p	(f) Industry 1,.......q	(g) Wastage 1,.......r	(h) Fertiliser N-P-K 1,.......s	(i) Pesticides 1,........t	(j) Labour 1,........u	(k) Environmental Outputs 1,.......v	(l) Deviational variable 1,.......x	(m) Deviational variable 1,.......z	Relationship	Right Hand Side
Constraints															
Linking Prod. And Market	$-a_{ij}$	+1	$+a_{ij}$	$-a_{ij}$	$+a_{ij}$	$+a_{ij}$	$+a_{ij}$							=	0
Transfer storage		$-a_{ij}$													
Fertiliser Requirements	$+a_{ij}$							-1						=	0
Pesticide Requirements	$+a_{ij}$								-1					=	0
Labour Requirements	$+a_{ij}$									-1				=	0
Storage Restrictions		+1												<=	Storage capacity
Sell Restrictions			+1											<=	Apples sold
Sell Restrictions			+1											>=	Apples sold
Import Restrictions				+1										<=	Apples imported
Export Restrictions					+1									>=	Apples exported
Industry Restrictions						+1								<=	Apples for industry
Wastage Restrictions							+1							<=	Apples for wastage
EIQ coefficients	$-a_{ij}$										+1			=	0
Land use	+1													>=	30% of existing var.
GOALS															
European Union Income	$-c_{ij}$	$-c_{ij}$	$+i_{ij}$	$-c_{ij}$	$+i_{ij}$	$+i_{ij}$	$+i_{ij}$	$-c_{ij}$	$-c_{ij}$	$-c_{ij}$		1	-1	=	Gross Margin Target
Environmental Pollution											1	1	-1	=	EIQ level Target
Labour supply										1		1	-1	=	Labour Target
OBJECTIVE FUNCTION (MIN deviational variables)												(1/target)* weight	(1/target)* weight		

3.7.2 Model constraints

The model constraints are indicated by rows in Table 3.9. The model is subject to constraints on marketing and yields, land, input requirements, losses and capacity of storage, and environmental coefficients (EIQ). The linkage between marketing and production is given by a set of constraints where production activities plus import activities must be greater or equal than the total apple sold for different purposes. Marketing and yield constraints are expressed by calendar month. In addition, maximum thresholds on sales volume of apples were incorporated, both by country and variety, in order to represent the registered monthly sales of apples. Otherwise, the model could sell most of the stock when the market shows the highest apple prices.

There are land constraints for each NUTS-2 region and for each variety, which specify that the total area of land under European apple cultivation be no more than the current situation.. In addition, fertiliser, pesticides and labour requirements were defined according to particular NUTS-2 region and variety.

In terms of land constraints, these are represented in two forms in the GP model: i) the amount of hectares under existing varieties, which is constrained to be at least 30% of the amount which there were in 1994, ii) the total hectares with both existing and new varieties which is constrained to be no more than the total land under apples in 1994 (see Table 3.10). These constraints were incorporated in order to evaluate how new variety competes with the existing varieties for the land use without varying the existing hectares under apple cultivation. Nevertheless, this restriction was not incorporated when the model was validated as is explained in Chapter 4. The GP model is forced to choose at least 30% of the existing apple varieties because this study does not take into account the potential adoption process of the new apple variety.

Table 3.10 Land use constraints

	Hectares under existing apple varieties cultivation (by NUTS)					New Variety		
Varieties and NUTS	1	1	1	1	1	1	<=	Hectares base year
	1						>=	Hectares base year x 0.3
		1					>=	Hectares base year x 0.3
			1				>=	Hectares base year x 0.3
				1			>=	Hectares base year x 0.3
					1		>=	Hectares base year x 0.3

The supply of apples is divided across producing and importing activities. Within the model, this must at least be equal to the total demand activities. The demand activities are: domestic consumption, storage, exports, apples for industry and other uses and wastage. The storage activity provides both demand for apples when the fruit goes into cold store for keeping purposes and supply of apples when apples are sold out of store to the market (see Table3.11).

Domestic apple consumption is constrained at maximum level of consumption per country, per variety and per month. The rationale of this was explained above.

As is shown in Figure 3.3 the imports and exports of apple taken into account in the model are only those from outside European Union. The imports are constrained by month and variety to the maximum import level of apples for the base year, assuming that countries do not want to increase the import of apples. Imports are penalised since they were attached with negative coefficient in the economy function. (European Union Income Table 3.9). On the contrary, the exports of apples have been constrained to a minimum export level for the base year, assuming that, European countries would want to maximise its export after domestic market is supplied . The same as imports, the exports have been constrained by month and variety.

As mentioned above, the amount of apple for industry is fixed at 15 % of the total production. It was not possible to get reliable information about the volume of apples marketed for processing. This percentage was extrapolated from reliable information collected in Spain (Apple co-operative Costa Brava, pers. communication). Only a few EU countries supplied us with this information.

Production inputs were split into fertiliser, pesticide and labour. At the same time, fertiliser was split into Nitrogen, Phosphorous and Potassium; pesticide was split into fungicide, insecticide and others and labour was split into pruning, harvesting and others. In addition, the model incorporates a tie-line linking production inputs to their cost. This allows us to change both technical coefficients of production and the prices of inputs. This is shown in Table 3.12.

Table 3.11 Market interactions by month

	Existing Varieties by NUTS-2				Storage by month											Domestic market	Industry demand	Wastage	Imports		
January					1										-Losses 1					=	0
February					-Losses	1														=	0
March						-Losses	1													=	0
April							-Losses	1												=	0
May								-Losses	1											=	0
June									-Losses	1										=	0
July										-Losses	1									=	0
August	-Yield/ha	-Yield/ha	-Yield/ha	-Yield/ha							-Losses					1	1	1	1	=	0
September												1								=	0
October												-Losses	1							=	0
November													-Losses	1						=	0
December														-Losses	1					=	0
Market Ties																1	1	1	1	<=>	Fixed values
Storage ties								1												<=	Storage capacity
					Cost of storage per tonne											Monthly prices per tonne					

Table 3.12 Apple production inputs and environmental outputs

	Existing and new varieties	Fertiliser	Pesticide	Labour	EIQ by NUTS and Variety		
Production Inputs ties		-1				=	0
		-1				=	0
	Technical coefficients	-1				=	0
	Fertilisers (N,P,K)		-1			=	0
	Pesticides (Fungicides, Insecticides, Herbicides, Others)		-1			=	0
	Labour (Pruning, Harvest, Others		-1			=	0
				-1		=	0
				-1		=	0
	Environmental coefficients			-1		=	0
	- EIQ Field-workers				1	=	0
	- EIQ Consumers				1	=	0
	- EIQ Environment				1	=	0
	Cost of apple production excluding Fertiliser, Pesticide and Labour	***Cost of inputs per unit***					

3.7.3 Attributes, Goals and Targets

This model is designed to determine what the social, economic and environmental impact of introducing a new technology[21] will be. Five attributes were identified as being relevant parameters to this problem: income, environmental conditions for pollution at field-workers, consumers and ecology and labour.

The targets corresponding to each of these attributes generate the goals and they are shown in Table 3.13. As Chapter 5 will explain, the final GP model was run only taking into account five European apple producing countries (i.e. Italy, France, Germany, Spain and Greece). Therefore, the targets presented in Table 3.11 just relate to these EU Member States. Maximisation of the income goal is achieved by setting the target level at an artificially high level of 690 million ECUs. On the contrary, minimisation of pollution goal is achieved by setting the target level at an artificially low level of 1530 million EIQ units. Finally, the target corresponding to labour attribute represents the existing use for the five EU selected countries.

Table 3.13 Targets corresponding to each selected goals.

Attributes	Goals					
	Italy	France	Germany	Spain	Greece	EU5
Income ('000 ECUs)	250000	180000	100000	100000	60000	690000
EIQ Total ('000 units)	672000	536681	24500	270358	26600	1530139
EIQ P (million units)	100000	157131	4000	38610	3600	303341
EIQ C ('000 units)	57000	32041	2500	15968	3000	110509
EIQ E ('000 units)	515000	347510	18000	215780	20000	1116290
Labour ('000 Hours)	46457	51277	19672	23956	14828	156190

21 Introduction of new disease resistant apple varieties in the EU apple industry

Economic goal

The economic goal has been specified in this case to be the maximisation of the income from the EU apple industry. Income is defined as gross revenue less the variable costs of apple production. Fixed costs are not taken into account because there is considerable variation between Member States in the EU and indeed between different regions and farmers. Negative coefficients in Table 3.9 represent the variable costs of apple production while total income is represented by positive coefficients. The income goal is therefore expressed in ECU as:

G_1 = *Maximisation of Income*, thus the objective function minimises n_1 (deviational variable), allowing the model an over-achievement of this goal and it has the following mathematical expression:

$$G_1 = \sum_{i=1}^{n}(D_{vm}P_{vm}) + (E_{vm}P_{vm}) + (ID_{vm}P_{vm}) - \sum_{i=1}^{n} Y_v H_v C_v + n_1 - p_1 = T_1 \qquad (3.8)$$

Where;

P_{vm}= price of v varieties and sold in month m

D_{vm}= apple v varieties sold in the domestic market in month m

E_{vm}= apple v varieties exported in month m

ID_{vm}= apple v varieties sold them to industry in month m

Y_v= apple yield in tonnes/ha by variety

H_v= the number of hectares by variety

C_v= the cost of production in ECUs/hectare by variety

T_1= economic target

Environmental goals

The three environmental goals in the GP model were broadly to minimise environmental pollution due to the use of pesticides for growing apples. Pollution is measured and expressed in EIQ units. The positive deviational variables were minimised in the objective function and the goal was split in three components according to the Kovach *et al.*, (1992) formula:

G_2= *Minimisation of EIQ P* (field-workers), the objective function minimises p_2 thus, an under-achievement of the variable is not penalised and it is expressed as;

$$G_2 = \sum_{v}\sum_{N} H_{vN} EIQP_{vN} + n_2 - p_2 = T_2 \tag{3.9}$$

Where;

H_{vN}= the number of hectares of the v variety in the N NUTS-2
$EIQP_{vN}$= the EIQ value (field-workers) of the v variety in the N NUTS-2
T_2= EIQ field-workers target

G_3= *Minimisation of EIQ C* (consumers), the objective function minimises p_3 thus, an under-achievement of the variable is not penalised and it is expressed as;

$$G_3 = \sum_{v}\sum_{N} H_{vN} EIQC_{vN} + n_3 - p_3 = T_3 \tag{3.10}$$

Where;

H_{vN}= the number of hectares of the v variety in the N NUTS
$EIQC_{vN}$= the EIQ value (Consumers) of the v variety in the N NUTS
T_3= EIQ consumers target

G_4= *Minimisation of EIQ E* (apple orchard environment), the objective function minimises p_4 thus, an under-achievement of the variable is not penalised and it is expressed as;

$$G_4 = \sum_{v} \sum_{N} H_{vN} EIQE_{vN} + n_4 - p_4 = T_4 \tag{3.11}$$

Where;

H_{vN}= the number of hectares of the v variety in the N NUTS

$EIQE_{vN}$= the EIQ value (Environment) of the v variety in the N NUTS

T_4= EIQ apple orchard environment target

Social goal

This goal was set by means of labour demand at the farm level and it is expressed in hours.

In terms of setting this goal to a target, three approaches can be followed to define the objective for labour. First, the model could be defined to maximise labour use. This option would increase the labour demand and therefore be seen as socially desirable, but would increase the cost of apple production, thus impacting on the income goal. As an alternative, the minimisation of labour could be adopted but this option would simply increase unemployment in the European union apple industry. The alternative approach is to maintain the current level of labour as the assumed optimum. Consequently, in the objective function, both negative and positive variables are minimised [22] and the ideal target (the status quo, 1994) will be matched as closely as possible.

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22 Romero,(1991), called "two-side goals" when the decision-makers dislikes both under and over-achievement to the target. In addition, he suggested that two-side goals must only be used when an exact achievement of the target is desired, (e.g. this is the case of labour target in the GP apple model). Otherwise, the model can lead to sub-optimal solutions.

G_5=*Labour target,* the objective function minimises both, n_5 and p_5. Therefore, it penalises both under and over-achievement.

$$G_5 = \sum_v \sum_N H_{vN} L_{vN} + n_5 - p_5 = T_5 \qquad (3.12)$$

Where;

H_{vN}= the number of hectares of the *v* variety in the *N* NUTS

L_{vN}= the number of hour needed for producing *v* variety in the *N* NUTS

T_5= labour use target

3.7.4 Objective function

In general, the solution to a GP is comprised of the optimal level of activities based on satisfying concurrent goals. To arrive at this solution, deviations from the desired goals need to be minimised. Consequently, the model includes an objective function which minimises the weighted sum of deviations between the individual objective function and their corresponding desired target level and it is expressed as;

$$Minimise Z = W_1 n_1 + W_2 p_2 + W_3 p_3 + W_4 p_4 + (W_5 n_5 + W_5 p_5) \qquad (3.12)$$

Where;

$W_{1\text{-}5}$= weights attached to the deviations of the goals from *G* 1 to 5

$n_{1\text{-}5}$= negative deviational variables from *G* 1 to 5

$p_{1\text{-}5}$= positive deviational variables from *G* 1 to 5

Weights are variable and the sensitivity of the model results to these variations will be discussed in Chapters 5 and 6.

3.7.4.1 Normalising the goals

According to Romero and Rehman (1989) and Romero (1991), in most WGP problems the goals making up the model are measured in different units. In this study, goals are measured in ECUs, EIQ units and hours of labour. Under this situation, the objective function is meaningless as a sum of deviational variables expressed in different units. However, these authors notice that an additional problem in WGP arises when the targets associated with each goal have different absolute numerical values. They support that (in this situation) the solution derived from the model can be biased as more importance is given to the goals with higher target values than those with lower ones. Therefore, these goals artificially receive extra-weight, which does not necessarily reflect the decision-maker's preferences. In this study, the environmental targets are very high if they are compared with the others, simply because they have high absolute values per hectare.

In order to avoid the problems presented above, Romero (1991) suggests two methods for normalisation of the deviational variables: scaling based on percentage and the Euclidean norms. The first, expresses the goals in relative terms rather than of absolute terms. So, the objective function becomes meaningful as it sums percentages, which are a-dimensional and the new set of weights do represent the preference of the DM. However, the problem that remains is the necessity to distinguish between the numerical value of the deviation and its corresponding geometric distance, which is taken into account by adjusting each goal according to Euclidean norms.

The Euclidean norming procedure was rejected because it presents two problems. First, the objective function still has different units, and second, it does not consider the numerical values of the goals which means solutions can still be biased owing to artificial extra-weights for goals with high numerical values. According to this, the percentage norming procedure was adopted for this study.

Therefore, to normalise a WGP model according to the norming procedure selected, model (3.12) is changed to the following;

$$MinimiseZ = \frac{n_1}{b_1}W_1 + \frac{p_2}{b_2}W_2 + \frac{p_3}{b_3}W_3 + \frac{p_4}{b_4}W_4 + \frac{n_5}{b_5}W +_5 \frac{p_5}{b_5}W_5 \qquad (3.13)$$

Where;

$W_{1\text{-}5}$= weights attached to the deviations of the goals from G 1 to 5

$n_{1\text{-}5}$= negative deviational variables from G 1 to 5

$p_{1\text{-}5}$= positive deviational variables from G 1 to 5

$b_{1\text{-}5}$= target values expressed in different units for each goal

So far, the model was described and the next Chapter will show the data availability and validation model for the five EU countries selected for this study. In addition a brief overview of the apple industry in each country is presented.

Chapter 4
The Apple Industry in the five EU Selected Countries: Data Availability, Model Calibration and Validation

This chapter presents an overview of the apple industry of the European countries that have been selected for inclusion in the GP model. Greece, Italy, France, Germany and Spain have been selected from the twelve European countries. Two main reasons influenced the choice of this selection. First, these five countries together represent approximately 90% of total EU apple production and 75% of the total EU land area of apple production. Second, from a practical point of view, reliable data was only available for these EU countries. The following sub-sections describe the apple industry for each country separately, showing the information that was obtained. Sections 4.1 and 4.2 describe storage technology and cost of production in general terms, whilst Sections 4.3 to 4.7 describe each country in more detail. The validation of the model is presented in section 4.8 as a conclusion to the chapter.

4.1 Storage technology

Storage of fresh apples requires considerable managerial and technical skill. A fresh apple, once harvested and left at ambient temperature, will deteriorate at a linear rate, becoming soft, dry and shrivelled (O'Rourke, 1994). There are two main systems for storing apples. These systems are regular atmosphere (RA) and controlled atmosphere (CA). While the first maintains apples at a uniform low temperature, the second controls humidity and carbon dioxide as well as temperature. Because of the use of CA, the marketing systems for many apple varieties have been transformed. For example, in the early 1950s, most of Red Delicious had to be sold within four months of harvest, whereas, by the early 1970s, it was possible to hold this variety up to the following harvest (O'Rourke, 1994). Unlike CA, fruit of good quality can only be marketed out of RA storage for three or four months. In addition, and quite importantly for this study, the rate of storage losses differs between storage systems. Unfortunately, data relating to the use of either RA or CA systems is poorly defined at national and EU levels and, as a consequence, model coefficients relating to storage capacity and the cost of storage assumed that one system existed in the EU apple industry and the monthly rate of losses was estimated in 0.33%. Table 4.1 shows the costs of storage per month and per tonne used within the model.

Table 4.1 Cost of apple storage

Country	ECU/month/tonne
Italy	10.2
France	12.0
Germany	7.58
Spain	12.0
Greece	10.2*

Source: ZMP; Cooperativa de Fruticultores COSTA BRAVA; Confcooperative (1993)

(*) Assumed to be the same as the cost of storage in Italy, due to a lack of data.

4.2 Cost of production

The economics of apple production, as indeed with any perennial cash crop, can be extremely complicated. Commercial growers in the European Union range from the full time commercial farmers cultivating 25 to 35 hectares in the UK and Germany, to the small scale, often part time, farmers cultivating less than half of one hectare in Greece. The economic conditions facing these two types of producer are clearly quite different, and yet certain underlying principles hold true for both types of production.

Firstly, a considerable time lag exists between planting and harvesting. This time lag can be anywhere from six to ten years depending on the training system, tree densities[22] and the growing conditions. Thus, the costs of establishing an orchard must be charged to the orchard during its productive years (depreciation), which may be up to twenty five years. Secondly, production, and quality of product, may vary greatly from year to year. This phenomenon can be due to any number of reasons from winter frost, to diseases and pests, to hail storms (Winter and Welte, 1986; Winter, 1989). Smaller units can suffer a great percentage variability in production, and therefore may not be able to cope as well as larger production units. To compound these problems apples, like many perennials, suffer from a situation where an above average crop yields are followed by below average yields (O'Rourke, 1994). Therefore, the average cost per unit output will vary greatly from year to year.

Apples are not a homogenous product, varying in quality, size, taste and colour. Market values of the product are based on quality, with fruit sold for juices and processing attracting much less in price than fruit for fresh consumption (Fenmore and Norton, 1985). In addition to this, in order to ensure the quality of the fruit, the farmer may incur additional costs in terms of increased pesticide use and pruning and thinning, to help guarantee quality. Therefore, in order to increase profits and revenue, the farmer will necessarily incur additional absolute higher variable costs.

Production costs vary between Member States in the EU, and indeed between different regions within individual Member States (see Table 4.2 and Appendix 1.2). For instance, the production costs associated with large scale, intensive apple cultivation in the Alto Adige[23] region of Northern Italy are likely to be significantly different to the small scale, extensive apple production characteristics of the Mezzogiorno region of Southern Italy. Many factors will combine to create regional differences in production costs, but the most important are: yield, selected cultivar, farm structure level of

[22] Number of apple trees per hectare
[23] Identified by N1 in the mode ECU

knowledge and experience of grower, land availability, level of wages, organisation of market, political influences (Winter, 1989).

4.2.1 Fixed, variable costs of production

Within the GP model, apple costs are categorised as fixed costs and variable costs, the sum of which combine to make total costs and the values correspond to one hectare per year. Fixed costs are those costs associated with fixed factors, defined as those independent of the level of output, and in particular, must be paid whether or not the orchard produces apples. Fixed costs in apple production include interest paid on investment for orchard establishment, building costs, machinery costs, land rent or taxes, management cost, depreciation and insurance (Gittinger, 1982).

Costs listed under variable costs are those costs that change as the output of the orchard changes and reflect the annual cash costs incurred during the year. These costs include casual labour (harvest, pruning and others), pesticide and fertiliser use, machinery hire or purchase, fuel and irrigation. Appendix 1.2 presents both variable and fixed cost for each EU country. Annual total costs, consequently, is the sum of fixed and variable cost.

4.2.2 The cost of production in the GP model

The costs presented in Table 4.2 correspond to an average annual cost of production when the orchard has been established (when the apple trees have reached full production). The total cost of apple production depends on the system of production used, which is defined by different parameters such as, the varieties selected, the number of trees per hectare planted and the irrigation system chosen. It was not possible to get information about cost of production by production apple systems. As a consequence, the model was run with an average cost of the existing apple systems. At the same time, the cost of production used in the model has been split into two components. First, for each region and variety the corresponding cost of production was defined as the total production costs minus pesticide, fertiliser and labour costs. The resulting figures are shown in Table 4.2.

On the other hand, the model has included the remaining costs, i.e. pesticides, fertilisers and labour. In turn, pesticide was split into fungicide costs, insecticide costs, herbicide costs and other (such as physiological regulators). In the same way, fertiliser costs were divided into nitrogen, phosphorus and potassium costs. Finally, labour costs were split into harvest, pruning and others. With regard to pesticide costs, the figures used in the model were calculated by multiplying the kilos of pesticides by the weighted costs per kilo, following the methodology explained in chapter 3. This allowed us to easily make changes in the level of pesticide, fertilisers and labour usage for sensitivity analysis (see Chapter 6).

Table 4.2 Cost of production by country, by region and by apple variety (expressed in ECU[24])*

Italy	ECU/ha	France	ECU/ha	Germany	ECU/ha	Spain	ECU/ha	Greece	ECU/ha
IN1GD	3500	FN1GD	2752.38	GYN1GD	3543.3	SN1GD	2580	GN1GD	1987.86
IN1RD	3500	FN1RD	2752.38	GYN1BP	3508.3	SN1RD	2580	GN1RD	2132.98
IN1OT	3500	FN1GS	2752.38	GYN1GL	3665.3	SN1OT	2580	GN1OT	1654.11
IN2GD	4615.1	FN1OT	2752.38	GYN1JG	3612.9	SN2GD	3420	GN2GD	1987.86
IN2RD	4615.1	FN2GD	4402.6	GYN1OT	3473.68	SN2RD	3420	GN2RD	2132.98
IN2IM	4615.1	FN2RD	4402.6	GYN2GD	3543.3	SN2OT	3420	GN2OT	1654.11
IN2OT	4615.1	FN2GS	4402.6	GYN2BP	3508.3	SN3GD	3180	GN3GD	1987.86
IN3GD	4615.1	FN2OT	4402.6	GYN2GL	3665.3	SN3RD	3180	GN3RD	2132.98
IN3RD	4615.1	FN3GD	2752.38	GYN2JG	3612.9	SN3OT	3180	GN3OT	1654.11
IN3IM	4615.1	FN3RD	2752.38	GYN2OT	3473.68				
IN3OT	4615.1	FN3GS	2752.38	GYN3GD	3543.3				
IN4GD	4615.1	FN3OT	2752.38	GYN3BP	3508.3				
IN4RD	4615.1	FN4GD	2752.38	GYN3GL	3665.3				
IN4IM	4615.1	FN4RD	2752.38	GYN3JG	3612.9				
IN4OT	4615.1	FN4GS	2752.38	GYN3OT	3473.68				
		FN4OT	2752.38	GYN4GD	3543.3				
		FN5GD	2752.38	GYN4BP	3508.3				
		FN5RD	2752.38	GYN4GL	3665.3				
		FN5GS	2752.38	GYN4JG	3612.9				
		FN5OT	2752.38	GYN4OT	3473.68				
				GYN5GD	3543.3				
				GYN5BP	3508.3				
				GYN5GL	3665.3				
				GYN5JG	3612.9				
				GYN5OT	3473.68				

Sources: Confcooperative Unione di Ravenna; E.S.A.T. Trento; Centro Operativo Ortofruticolo Ferrara (1992);Universita di Torino (1984);C.T.I.F.L. (1990;1995);CEMAGREF (1994);ZMP (1994); Universidad Politecnica de La Almunia; Costa Brava co-coperative;University of Thessaloniki.

(*) Appendix 3.4 shows the corresponding apple variety codes

[24] Most of the information received was expressed in national currency. Therefore, national currency should be converted into ECU. The unit rates utilised were; 1 Franc = 6.54024 ECU, 1 Lira = 2106.15 ECU, 1 Peseta = 161.902 ECU, 1 Mark = 1.86408 and, 1 drs = 301.538 (the Financial Times 19-6-1995).

4.3 The Greek apple industry

Greece is one of the poorest countries in the EU, and its apple industry is dominated by small-scale family farms with and averages of almost 0.5 ha. The total Greek area under apples is about 12,000 hectares representing 3.6% of the total EU apple land area. The apple production accounts for only 3.8% of the whole EU apple production. Despite Greece being one of the smallest apple producers in the EU, it was included in this study mainly because of the reliable data received from the University of Thessaloniki. The Department of Agricultural Economics Research that belongs to this University, conducted a field survey in order to gather information about the Greek apple industry. A questionnaire was designed including questions about apple varieties, area under apple cultivation, Greek region, fertilisers, pesticides, labour and, costs of production. More than sixty farmers were interviewed in the region of Thessalia (N1) and Kentriki Makedonia (N2). These two regions represent approximately 70% of total Greek apple production.

Basically, ten apple varieties are grown in Greece with Golden Delicious (GD) being the most important variety cultivated. This apple variety alone accounts for almost the 75% of the total Greek production. Nevertheless, the model activities were split into Golden Delicious, Red Delicious (RD) and Others (OT). It was not possible to get information about apple varieties by NUTS-2. Thus, total Greek area by variety, was divided by three, representing the three NUTS-2 chosen (see Table 4.3). Tables 4.3 to 4.5 summarise the received information from the university of Thessaloniki survey.

Demand for apples in Greece has been subdivided (the same was done for all EU countries) into four activities: domestic market; industry; exports; and wastage. The sale price of apples varies from one month to another and from one variety to another. Therefore, the level of detail for the model was expanded into monthly periods by variety. However, too little data could be obtained, from too few countries (Greece and Spain) to provide a reliable picture of the monthly changes in the apple industry by variety. It was assumed that 70% of the Greek apple production is for fresh consumption in the domestic market (O'Rourke, 1994). With regard to processing apples, it was assumed that 15% of the production is for processing use, being the same value as Spain. The apple price paid by the Greek industry was again the same that was obtained from the Spanish industry.

Table 4.3 Greek apple land use, production and yield

NUTS & Varieties	Hectares	Yield Tonnes/ha	Production Tonnes
G1GD	2920.80	24.9	72727.92
G1RD	573.60	23.9	13709.04
G1OT	505.6	26.9	13600.6
G2GD	2920.8	27.3	79737.8
G2RD	573.6	25.1	14397.4
G2OT	505.6	24.5	12387.2
G3GD	2920.8	23.5	68638.8
G3RD	573.6	28.59	16399.22
G3OT	505.6	21.3	10769.3
Total	12000		302367.28

Source: Adapted from University of Thessaloniki and C.O.O. 1994

Table 4.4 Greek apple prices by variety and by use

Month	Golden Delicious ECU/tonne	Red Delicious ECU/tonne	Others ECU/tonne	Industry All varieties ECU/tonne	Imports All varieties ECU/tonne
January	531	305	405	79.6	600
February	485	279	371	79.6	600
March	574	330	439	79.6	600
April	595	342	455	79.6	600
May	661	380	505	79.6	600
June	873	502	668	79.6	600
July	1192	685	911	79.6	600
August	551	317	422	79.6	600
September	353	203	270	79.6	600
October	308	177	235	79.6	600
November	331	190	253	79.6	600
December	353	203	270	79.6	600

Source: Adapted from University of Thessaloniki

Table 4.5 Pesticides, Fertilisers and Labour use in the Greek apple industry

	Golden Delicious			Red Delicious			Others		
	N1	N2	N3	N1	N2	N3	N1	N2	N3
Nitrogen units/ha	298	395	491	214	434	380	310	585	485
Phosphorus units/ha	123	96	0	116	169	0	50	230	0
Potassium units/ha	165	497	0	137	531	0	150	521	0
Fungicides kg/ha	22.38	40.17	9.24	11.33	36.16	12.37	8.6	29.63	9.1
Insecticides kg/ha	7.26	13.71	6.23	9.16	8.62	8.96	4.19	9.45	6.36
Herbicides kg/ha	1.28	0	0.12	0.93	0	0.25	0.55	0	0
Others kg/ha	0	0	0	0.46	0	0	0.87	0	0
Harvest hours/ha	197	966	377	355	875	428	515	799	510
Pruning hours/ha	173	294	121	180	350	120	226	305	107
Others hours/ha	382	875	250	513	667	268	429	906	270
EIQ P units/ha	610.7	1115.6	435.7	481.7	1027.5	504.5	421.7	883.9	694.2
EIQ C units/ha	169.4	338	111.1	126.4	308.6	134.1	106.4	260.7	197.4
EIQ E units/ha	1299.8	2139.2	1009.0	1085.4	1992.8	1123.4	985.6	1754.1	1438.7
EIQ total units/ha	2080.1	3592.8	1555.8	1693.4	3328.8	1761.9	1513.6	2898.7	2330.3

Source: Adapted from University of Thessaloniki

4.4 The Italian apple industry

The Italian apple industry is amongst the four highest performing in the EU, in terms of total production and yield per hectare. Italian apple production is concentrated within three main regions located in the north of the country, where almost the 70% of the Italian apple production takes place. These regions are Trentino-Alto Adige, Emilia-Romagna and Veneto. The combined production of these three regions amount to approximately 1.5 million tonnes. Such Italian regions were included in the model being identified by N1, N2 and N3 respectively (see Table 4.6). For instance, Trentino region produces 20% of the entire national production and 5% of European production (A.P.O.T., 1992; C.O.O., 1993).

The majority of the Italian production is geared towards the fresh market. Fresh production represents over 60% of total production (Castaldi and Segre, 1990). The

Italian production is dominated by the Golden Delicious and Red Delicious varieties. These two varieties account for 49% and 19% of the total production respectively. However, in more recent years, plantings of Granny Smith, Jonagold and Gala varieties has increased (Prognosfruit, 1994).

In terms of storage capacity, a total of 522 storage facilities exist for fresh fruit storage. These 522 facilities have a combined storage capacity of 2,045,838 metric tonnes representing, both regular and controlled atmosphere storage. Of the total, controlled atmosphere accounts for over 60% of the total while regular storage accounts for the balance (Castaldi and Segre, 1990).

With regard to yields and land use, table 4.6 shows the corresponding numerical value used in the model. The existing apple varieties have been grouped into Golden Delicious (GD), Red Delicious (RD), Imperatore de Roma (IM) and others (OT). The first three varieties account for approximately the 75% of the total Italian apple production whereas other varieties account for the remaining 25%.

Table 4.6 Italian land use, production and yield

NUTS2 & Varieties	Hectares	Yield Tonnes/ha	Production Tonnes
I1GD	20591.43	25.97	534759.44
I1RD	3111.33	20.22	62911.09
I1OT	5484.24	20.83	114236.72
I2GD	2857.11	25.97	74199.15
I2RD	5141.72	20.22	103965.58
I2IM	1649.67	32.83	54158.67
I2OT	4144.5	20.83	86329.94
I3GD	4244.25	30.26	128431.01
I3RD	2523.9	28.53	72006.87
I3IM	2375.37	28.86	68553.18
I3OT	2415.48	26.74	64589.94
I4GD	10501.79	35.6	373863.72
I4RD	5746.07	33.28	191229.21
I4IM	3292.85	29.82	98192.79
I4OT	6025.52	41.08	247528.36
Total	80105.23		2274955.67

Source: Prognosfruit 1994

Table 4.7 presents the corresponding prices per tonne for the different apple uses. In this particular case, the figures presented in Table 4.7 account for the average for the whole year. Industry prices and export prices are assumed to be the same as the figures obtained for Spain.

Obviously, the domestic consumption of apple is not fixed each year, but varies around an average consumption, depending mainly on both the price of apples and the price of other alternative tropical fruits. In the model, the domestic consumption was constrained at a fixed level of 1,950,466.84 tonnes per year, representing the amount of apple consumed in 1994. Similarly, exports were constrained at 29,313.68 tonnes as a minimum value. Exports can be increased only after the domestic market demand has been met. The mentioned value corresponds to the figure obtained for 1994. Apples for processing were restrained at 15% of the entire apple production. It was not possible to get a reliable information about amount of apples for processing per year, as a consequence, it was again assumed to be the same value as Spain.

As mentioned above, the selected regional subdivision for EU countries is that at NUTS-2 level. Table 4.8 shows the data collected for Italy with regards to fertilisers, pesticides, labour and EIQ index. The model allows us to include information by variety and by NUTS-2. Despite this, it was not possible to get reliable information with this level of detail. For instance, the use of 70 units of Nitrogen (Table 4.8) corresponds to a specific variety and region. However, the same value was used for the rest of both, regions and varieties. The reason months were defined because the data did exist for at least one country (Greece) and the model was therefore specified across monthly intervals, even though it would seem unnecessary for this country (see Table 4.7).

Table 4.7 Italian apple prices by variety and use

Month	Golden Delicious (*) ECU/tonne	Red Delicious (*) ECU/tonne	Imperatore di Roma (*) ECU/tonne	Others (*) ECU/tonne	Industry All varieties ECU/tonne	Exports All varieties ECU/tonne
January	450	450	420	430	80	450
February	450	450	420	430	80	450
March	450	450	420	430	80	450
April	450	450	420	430	80	450
May	450	450	420	430	80	450
June	450	450	420	430	80	450
July	450	450	420	430	80	450
August	450	450	420	430	80	450
September	450	450	420	430	80	450
October	450	450	420	430	80	450
November	450	450	420	430	80	450
December	450	450	420	430	80	450

(*)Source: European Commission 1994

Fertilisers (N, P and K[25]) are expressed in units of each element per hectare. For instance, assuming a source of nitrogen with 26% of this element and being the applied amount of 100 kg/ha, so the total N units applied to the orchard will be 26.

The same absence of information occurred with regard to pesticides. Therefore, the data presented in Table 4.8 is taken as an average for both, varieties and regions.

[25] N= Nitrogen, P= Phosphorus and K= Potassium

Table 4.8 Pesticides, Fertilisers and Labour use for the Italian apple industry

Variety	Golden Delicious				Red Delicious				Imperatore Di Roma			Others			
NUTS-2	N1	N2	N3	N4	N1	N2	N3	N4	N2	N3	N4	N1	N2	N3	N4
Nitrogen units/ha	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70
Phosphorus units/ha	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
Potassium units/ha	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
Fungicides kg/ha	45	45	45	45	30	45	30	45	45	45	45	45	45	45	45
Insecticides kg/ha	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5
Herbicides kg/ha	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Others kg/ha	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13
Harvest hours/ha	333	265	333	333	333	265	333	333	265	333	333	333	265	333	333
Pruning hours/ha	130	153	170	170	130	153	170	170	153	170	170	130	153	170	170
Others hours/ha	168	83	83	83	168	83	83	83	83	83	83	168	83	83	83
EIQ P units/ha	2313.1	2313.1	2313.1	2313.1	1776.5	2313.1	1776.5	2313.1	2313.1	2313.1	2313.1	2313.1	2313.1	2313.1	2313.1
EIQ C units/ha	803.4	803.4	803.4	803.4	572.7	803.4	572.7	803.4	803.4	803.4	803.4	803.4	803.4	803.4	803.4
EIQ E units/ha	7143.7	7143.7	7143.7	7143.7	5299.0	7143.7	5299.0	7143.7	7143.7	7143.7	7143.7	7143.7	7143.7	7143.7	7143.7
EIQ total units/ha	10260.2	10260.2	10260.2	10260.2	7648.3	10260.2	7648.3	10260.2	10260.2	10260.2	10260.2	10260.2	10260.2	10260.2	10260.2

Source: Adapted from A.P.O.T., 1992 and Confcooperative, 1993

4.5 The French apple industry

France represents approximately 28% of the EU apple production. The French apple industry is modern, which is expressed by the fact that the average yield is the third highest in the EU (Prognosfruit, 1994). Apple area represents in France approximately 65.000 hectares (Prognosfruit, 1994)). Around 65% of the French apple production is concentrated in four regions (Aulagnier, 1994); i.e. southeast (Provence-Alpes-Cote D'Azur), southwest (Midi-Pyrenees and Aquitaine) and Val de Loire (Pays de la Loire). These regions are represented in the GP model by the following code; N1, N2, N3 and N4 respectively. The rest of regions were grouped under "others" and represented by N5.

The most important variety is Golden Delicious, followed by Granny Smith. These varieties account for almost the 60% of the total French apple production. However, varieties like Gala and Jonagold have been increased during the last decade

(Prognosfruit, 1994). Apples were the first fruit exported by France, and French exports account for half of the exchange within EU countries. In addition, France has established a good structure for the offer and it has good cold store equipment and a good transport network as well. Therefore, France can sell apples all the year. Because of its large production, France can maintain a regular supply of apples, mainly Golden Delicious and other varieties such as Gala, Fuji and Braeburn. Approximately 50.000 tonnes of apples are exported to outside EU countries, accounting for the 10% of the total apple exports of the EU.

Table 4.9 summarises hectares under apple cultivation, yield per hectare and total production by variety and by region in France. Numerical values of yield per hectare are again given as an average for the different French regions for the same data problems as mentioned for Italy. As a consequence, it had to be assumed that the same yield per hectare for each region was realised.

Table 4.9 French apple land use, production and yield

NUTS & Varieties	Hectares	Yield Tonnes/ha	Production Tonnes
N1GD	11882.71	31.24	371215.86
N1RD	2428.44	27.3	66296.41
N1GS	2076.23	35.21	73104.06
N1OT	2150.38	30.57	65737.12
N2GD	3965.05	31.24	123868.16
N2RD	662.54	27.3	18087.34
N2GS	1938.03	35.21	68238.04
N2OT	3332.24	30.57	101866.58
N3GD	3987.39	31.23	124526.19
N3RD	869.6	27.3	23740.1
N3GS	1025.12	35.21	36094.48
N3OT	1187.73	30.57	36308.91
N4GD	3386.21	31.24	105785.2
N4RD	1381.73	27.3	37721.23
N4GS	726.54	35.21	25581.47
N4OT	992.5	30.57	30340.73
N5GD	11533.78	31.24	360315.29
N5RD	2360.38	27.3	64438.37
N5GS	1975.98	35.21	69574.26
N5OT	6047.42	30.58	184930.1
Total	63910		1987769.9

Source: Adapted from Prognosfruit, 1994.

The domestic French consumption was restrained at 1,751,291.35 tonnes per year. This value represents an average of consumption level. Imports were fixed at 58,192.94 tonnes per year, while exports were constrained at 72,101.95 tonnes per year. Again, exports can be increased only if the domestic market has been fully supplied.

With regard to apples for processing, the model simulates a situation where the industry is supplied with apples during September to December. Apple price paid by the processing industry are taken to be the same as the national average apple price paid to Spanish farmers, again due to data gaps.

Table 4.10 represents the monthly distribution of apple prices by varieties and by apple demand expressed in ECU per tonne. Again, it was not possible to get prices by month, therefore, an average price for the whole year was assumed.

Table 4.10 French apple prices by variety and by use

Month	Golden Delicious (*) ECU/tonne	Red Delicious (*) ECU/tonne	Granny Smith (*) ECU/tonne	Others (*) ECU/tonne	Industry All varieties ECU/tonne	Imports All varieties ECU/tonne	Exports All varieties ECU/tonne
January	448.5	466.44	569.59	472.27	80	795.23	623
February	448.5	466.44	569.59	472.27	80	795.23	623
March	448.5	466.44	569.59	472.27	80	795.23	623
April	448.5	466.44	569.59	472.27	80	795.23	623
May	448.5	466.44	569.59	472.27	80	795.23	623
June	448.5	466.44	569.59	472.27	80	795.23	623
July	448.5	466.44	569.59	472.27	80	795.23	623
August	448.5	466.44	569.59	472.27	80	795.23	623
September	448.5	466.44	569.59	472.27	80	795.23	623
October	448.5	466.44	569.59	472.27	80	795.23	623
November	448.5	466.44	569.59	472.27	80	795.23	623
December	448.5	466.44	569.59	472.27	80	795.23	623

(*)Source: Adapted from C.T.I.F.L., 1995

Table 4.11 presents the values for fertilisers, pesticides, labour and EIQ units in the French apple industry. Despite the fact that each variety was subdivided in five regions, the values are the same, excluding N2 where reliable information of these parameters was available.

Table 4.11 Pesticides, Fertilisers and Labour use in the French apple industry

	Golden Delicious					Red Delicious					Granny Smith					Others				
	N1	N2	N3	N4	N5	N1	N2	N3	N4	N5	N1	N2	N3	N4	N5	N1	N2	N3	N4	N5
Nitrogen units/ha	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
Phosphorus units/ha	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
Potassium units/ha	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
Fungicides kg/ha	98.5	98.5	98.5	98.5	98.5	98.5	36.9	98.5	36.9	98.5	98.5	36.9	98.5	98.5	98.5	98.5	36.9	98.5	98.5	98.5
Insecticides kg/ha	7.8	7.8	7.8	7.8	7.8	7.8	8.5	7.8	7.8	7.8	7.8	8.5	7.8	7.8	7.8	7.8	7.8	8.5	8.5	8.5
Herbicides kg/ha	3.78	3.78	3.78	3.78	3.78	3.78	2.47	3.78	3.78	3.78	3.78	2.47	3.78	3.78	3.78	3.78	3.78	2.47	2.47	2.47
Others kg/ha	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Harvest hours/ha	352	352	352	352	352	416	416	416	416	416	302	302	302	302	302	416	416	416	416	416
Pruning hours/ha	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200
Others hours/ha	244	244	244	244	244	244	244	244	244	244	244	244	244	244	244	244	244	244	244	244
EIQ P units/ha	4669.8	4669.8	4669.8	4669.8	4669.8	4669.8	2057.0	4669.8	2057.0	4669.8	4669.8	2057.0	4669.8	4669.8	4669.8	4669.8	2057.0	4669.8	4669.8	4669.8
EIQ C units/ha	959.6	959.6	959.6	959.6	959.6	959.6	404.3	959.6	404.3	959.6	959.6	404.3	959.6	959.6	959.6	959.6	404.3	959.6	959.6	959.6
EIQ E units/ha	10399.4	10399.4	10399.4	10399.4	10399.4	10399.4	4401.6	10399.4	4401.6	10399.4	10399.4	4401.6	10399.4	10399.4	10399.4	10399.4	4401.6	10399.4	10399.4	10399.4
EIQ total units/ha	16028.8	16028.8	16028.8	16028.8	16028.8	16028.8	6862.8	16028.8	6862.8	16028.8	16028.8	6862.8	16028.8	16028.8	16028.8	16028.8	6862.8	16028.8	16028.8	16028.8

Source: Adapted from C.T.I.F.L., 1995

4.6 The German apple industry

German apple production accounts for approximately 13% of the whole EU apple production. However, between 1988 and 1993 German apple production dropped from 1,240,000 tonnes to 888,400 (-28.3%). The area used for apple production is approximately 38,000 hectares, accounting for the 12% of the EU, whilst the average yield per hectare is slightly above the EU average at 23.2 tonnes per hectare (Prognosfruit, 1994).

Although apples are cultivated in all of the German regions, Baden-Wurttemberg and Niedersachsen are the most important ones. These two regions when combined together account for almost 50% of the total apple area in Germany (ZMP, 1995). Unlike Italy, France, Spain and Greece, the information gathered from Germany was at NUTS1 level. The selected NUTS1 are; Baden-Wurttemberg (N1 in the model), Niedersachsen (N2), Sachsen-Anhalt (N3), Nordrhein-Westfalen (N4) and the remaining NUTS were grouped as "others" (N5).

Germany grows a great number of apple varieties. Despite this, they are uniformly allocated, in terms of area, the most important being; Gloster (GL), Jonagold (JG), Golden Delicious (GD) and Boskoop (BP). Table 4.12 shows the use of land, yield and production for the German apple industry, being the values used in the model.

Table 4.12 German apple land use, production and yield

NUTS & Varieties	Hectares	Yield Tonnes/ha	Production Tonnes
GY1GD	1127.2	20.8	23445.8
GY1BP	1438.84	24.7	35539.35
GY1GL	1626.71	27.69	45043.6
GY1JG	1854.35	24.7	45802.45
GY1OT	5003.9	22.75	113838.73
GY2GD	813.42	20.8	16919.14
GY2BP	1037.82	24.7	25634.15
GY2GL	1173.33	27.69	32489.51
GY2JG	1337.53	24.7	33036.99
GY2OT	3608.9	22.75	82102.48
GY3GD	406.67	20.8	8458.74
GY3BP	519.1	24.7	12821.8
GY3GL	586.88	27.69	16250.71
GY3JG	669.01	24.7	16524.55
GY3OT	1805.34	22.75	41071.49
GY4GD	241.12	20.8	5015.3
GY4BP	307.79	24.7	7602.41
GY4GL	347.98	27.69	9635.57
GY4JG	396.67	24.7	9797.75
GY4OT	1070.44	22.75	24352.51
GY5GD	1320.7	20.8	27470.6
GY5BP	1685.83	24.7	41640
GY5GL	1905.94	27.69	52775.48
GY5JG	2172.67	24.7	53664.95
GY5OT	5862.86	22.75	184930.1
Total	38321		965864.16

Source: ZMP, 1995

The domestic German consumption was restrained at 743,928 tonnes per year. In the same way as the rest of the EU countries, this value represents an average of consumption level during the whole base year of 1994. Imports have been fixed at

50,208 tonnes per year (FAO Yearbook, 1994), while exports have been constrained at 72,101.95 tonnes per year. Exports can be increased if the domestic market has been fully supplied.

With regard to apples for processing, approximately 20% of the entire German production is for processing purposes (O'Rourke, 1994). In this case, again, the model simulates a situation where the industry is supplied with apples during September to December. Apple price paid by the processing industry is taken to be the same as the national average apple price paid to Spanish farmers. This was because information received from Germany did not allow us to find out the producer price paid by industry.

Table 4.13 shows the monthly distribution of apple prices by varieties and by apple demand expressed in ECU per tonne. These values were used for running the GP model. Again, it was not possible to get prices by month, therefore, it was assumed the average price for the whole year.

With regard to the technical coefficients for pesticides, fertilisers, labour and EIQ for the German apple industry, Table 4.14 summarises the information that it was possible to get. For most of the parameters, only the average for a particular variety and a region was known, which meant that it was necessary to use the same technical coefficients for all apples varieties and German regions. Most of the secondary data refer to "apples" in generic term or refer to "Germany" without specification of the region.

Table 4.13 German apple prices by variety and by use

Month	Golden Delicious ECU/tonne	Boskoop ECU/tonne	Gloster ECU/tonne	Jonagold ECU/tonne	Others ECU/tonne	Industry All varieties ECU/tonne	Imports All varieties ECU/tonne	Exports All varieties ECU/tonne
January	463.8	471.96	351.91	452.39	606.12	90	795.23	623
February	463.8	471.96	351.91	452.39	606.12	90	795.23	623
March	463.8	471.96	351.91	452.39	606.12	90	795.23	623
April	463.8	471.96	351.91	452.39	606.12	90	795.23	623
May	463.8	471.96	351.91	452.39	606.12	90	795.23	623
June	463.8	471.96	351.91	452.39	606.12	90	795.23	623
July	463.8	471.96	351.91	452.39	606.12	90	795.23	623
August	463.8	471.96	351.91	452.39	606.12	90	795.23	623
September	463.8	471.96	351.91	452.39	606.12	90	795.23	623
October	463.8	471.96	351.91	452.39	606.12	90	795.23	623
November	463.8	471.96	351.91	452.39	606.12	90	795.23	623
December	463.8	471.96	351.91	452.39	606.12	90	795.23	623

Source: Adapted from European Commission, 1994.

Table 4.14 Pesticides, Fertilisers and Labour use in the German apple industry

	Golden Delicious					Boskoop					Gloster					Jonagold					Others				
	N1	N2	N3	N4	N5	N1	N2	N3	N4	N5	N1	N2	N3	N4	N5	N1	N2	N3	N4	N5	N1	N2	N3	N4	N5
Nitrogen units/ha	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40
Phosphorus units/ha	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
Potassium units/ha	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33
Fungicides kg/ha	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5
Insecticides kg/ha	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
Herbicides kg/ha	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Others kg/ha	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Harvest hours/ha	233	233	233	233	233	224	224	224	224	224	266	266	266	266	266	238	238	238	238	238	230	230	230	230	230
Pruning hours/ha	120	120	120	120	120	90	90	90	90	90	90	90	90	90	90	100	100	100	100	100	100	100	100	100	100
Others hours/ha	151	151	151	151	151	178	178	178	178	178	193	193	193	193	193	178	178	178	178	178	179	179	179	179	179
EIQ P units/ha	235.5	235.5	235.5	235.5	235.5	235.5	235.5	235.5	235.5	235.5	235.5	235.5	235.5	235.5	235.5	235.5	235.5	235.5	235.5	235.5	235.5	235.5	235.5	235.5	235.5
EIQ C units/ha	125.1	125.1	125.1	125.1	125.1	125.1	125.1	125.1	125.1	125.1	125.1	125.1	125.1	125.1	125.1	125.1	125.1	125.1	125.1	125.1	125.1	125.1	125.1	125.1	125.1
EIQ E units/ha	795	795	795	795	795	795	795	795	795	795	795	795	795	795	795	795	795	795	795	795	795	795	795	795	795
EIQ total units/ha	1155.6	1155.6	1155.6	1155.6	1155.6	1155.6	1155.6	1155.6	1155.6	1155.6	1155.6	1155.6	1155.6	1155.6	1155.6	1155.6	1155.6	1155.6	1155.6	1155.6	1155.6	1155.6	1155.6	1155.6	1155.6

Source: ZMP, 1995

4.7 The Spanish apple industry

Information about the Spanish apple sector was difficult to obtain. As a consequence, the data utilised for this study was obtained by contacting marketing organisations, visiting apple producing regions and talking to research stations. The institutions visited during 1996 were; Escuela Politecnica La Almunia de Doña Godina (Aragon), Cooperativa Fruticola EMPORDA (Cataluña), Cooperativa de Fruticultores COSTA BRAVA (Cataluña), FRIFRUIT, (Cataluña) and Agrupacio de Cooperatives de les Terres de Lleida, ACTEL, (Cataluña).

Spain is the fourth most important apple producer within the EU. The Spanish apple production has ranged between 500,000 and 1,000,000 tonnes per year from 1988 to 1993 (Prognosfruit, 1994). Almost 60% of the Spanish apple area is located in the Northeast of the country, accounting for 75% of the total Spanish production. Cataluña (N1) and Aragon (N2) are the most important apple producer regions, although Asturias is the third important region in Spain, it was not included because it mainly produces a local apple variety only for processing use. Consequently, just the mentioned NUTS-2 were included in the model for Spain. The rest of the country was represented as a single region (N3).

Golden Delicious (GD) and Red Delicious (RD) are the most important varieties in the Spanish apple industry. These varieties combined represent almost 80% of the total Spanish production (Prognosfruit, 1994). Table 4.15 presents the number of hectares under apple cultivation with the corresponding yield and production, by NUTS2 and by variety for the base year 1994.

Table 4.15 Spanish apple land use, production and yield

NUTS & Varieties	Hectares	Yield Tonnes/ha	Production Tonnes
SN1GD	8815	28.2	248583
SN1RD	3666	27.74	101694.84
SN1OT	2666	27.56	73474.96
SN2GD	1726	22.27	38438.02
SN2RD	2517	44.09	110974.53
SN2OT	4549	17.47	79471.03
SN3GD	9288.4	11.8	109603.1
SN3RD	6967	10.7	74546.9
SN3OT	2323	20.74	48179.02
Total	42517.4		884965.4

Source: Prognosfruit, (1994); Generalitat de Catalunya Departament d'Agricultura, Ramaderia I Pesca, (1993); Escuela Universitaria Politecnica La Almunia de Dona Godina, (1994).

The Spanish sub-model was constrained at 855,111.68 tonnes of domestic consumption per year. In addition, the amount of processing apples was constrained as at least 15% of the total Spanish production, September to December being the period where the industry is supplied with apples. The Spanish exports to outside EU countries were fixed at least 1,248 tonnes per year. Again, the model allows exports to be increased once the domestic market is supplied. The apple prices paid by both industry or fresh market were obtained from the fruits' co-operatives of Cataluña and Aragon. In this particular case, it was possible to get data by month and by variety, as is shown in Table 4.16. Nevertheless, information about imports, exports and industry monthly prices and by variety was difficult to obtain, and again, annual averages were assumed.

Table 4.17 shows the technical coefficients used in the Spanish model. It was not possible to get information about pesticides, fertilisers and labour by variety in spite of the visits made to the Spanish co-operatives. As a result, the same level of pesticides, fertilisers and labour usage was applied for all varieties.

Table 4.16 Spanish apple prices by variety and by use

Month	Golden Delicious ECU/tonne	Red Delicious ECU/tonne	Others ECU/tonne	Industry All varieties ECU/tonne	Imports All varieties ECU/tonne	Exports All varieties ECU/tonne
January	400	400	400	79.6	600	450
February	400	400	400	79.6	600	450
March	400	400	400	79.6	600	450
April	460	460	460	79.6	600	450
May	460	460	460	79.6	600	450
June	460	460	460	79.6	600	450
July	460	460	460	79.6	600	450
August	460	460	460	79.6	600	450
September	300	300	300	79.6	600	450
October	300	300	300	79.6	600	450
November	300	300	300	79.6	600	450
December	300	300	300	79.6	600	450

Source:Lerida, La Almunia de Doña Godina and Costa Brava apple co-operatives, personal visit (1996)

Table 4.17 Pesticides, Fertilisers and Labour use in the Spanish apple industry

	Golden Delicious			Red Delicious			Others		
	N1	N2	N3	N1	N2	N3	N1	N2	N3
Nitrogen units/ha	75	90	90	75	90	90	75	90	90
Phosphorus units/ha	40	55	50	40	55	50	40	55	50
Potassium units/ha	125	140	140	125	140	140	125	140	140
Fungicides kg/ha	53.97	29.33	41.65	41.65	29.33	29.33	53.97	29.33	41.65
Insecticides kg/ha	4.85	4.93	4.89	4.85	4.93	4.89	4.85	4.93	4.89
Herbicides kg/ha	1.84	3.61	2.57	2.57	3.61	2.57	1.84	3.61	2.57
Others kg/ha	0.05	0.02	0.035	0.05	0.02	0.035	0.05	0.02	0.035
Harvest hours/ha	400	250	325	400	250	325	400	250	325
Pruning hours/ha	120	130	125	120	130	125	120	130	125
Others hours/ha	120	80	100	120	80	100	120	80	100
EIQ P units/ha	1009	652.8	830.9	830.9	652.8	652.8	1009	652.8	830.9
EIQ C units/ha	417.3	250.0	333.7	333.7	250.0	250.0	417.3	250.0	333.7
EIQ E units/ha	5639	3342.1	4490.3	4490.3	3342.1	3342.1	5639	3342.1	4490.3
EIQ total units/ha	7065.3	4244.8	5654.8	5654.8	4244.8	4244.8	7065.3	4244.8	5654.8

Source:Lerida, La Almunia de Doña Godina and Costa Brava apple co-operatives, personal visit (1996)

4.8 Model validation

Using the data described above, after building a mathematical model it would be necessary to validate it before using the results that it produces (Williams, 1993). A model cannot represent all of the perceived reality, therefore attention should be focused to that part of the reality which the model tries to represent (McCarl, 1984). Dent and Blackie (1979) remarked that the aim of validation is to determine if the model constructed is an adequate representation for our purposes. In this particular case the model is going to be used for evaluating changes to the European apple industry after introducing a new variety. As the new variety is a disease resistant variety, the evaluation is focused on environmental changes and how the model incorporates land under the new apple variety into the existing European apple industry.

The validation procedure involves comparing the performance of the model either against recorded data for the systems or against a subjective judgement of what the output should be, given a broad understanding of the system or type of system which the model represents (Dent and Blackie, 1979). Such validation has become known as validation by construct.

On the other hand, McCarl (1984) established two types of validation; technical validation and operational validation. While the first covers the testing of the internal consistency of the model, the second idea covers the testing of the actual utilisation of the model for practical purposes in different situations.

Most often, simple comparisons are made and measures of deviations are calculated (Hazell and Norton, 1986). For carrying out the comparisons, one simple and pragmatic strategy, as suggested by McCarl and Apland (1986), is to restrict the values of all activities (using constraints or bounds) to a set of values observed in the real world, then run the model to check whether the model solution is comparable with the current situation. If the solution is not reasonable, it is necessary to find out why and correct the problem.

Williams (1993) suggests that there are three possible outputs after constructing a model, i.e. (i) the model is *infeasible*, (ii) the model is *unbounded* and (iii) the model is *solvable*. These first results allow us to know about the correct structure of the model. In addition, the same author suggests that after obtaining the optimal solution to such a model it is important to know if the answer is sensitive and if it is not then there must be something wrong with the model. It is important to examine the optimal solution critically using common sense. This may well reveal an obvious error, which should enable us to detect and correct a modelling error.

In this study, validation of the goal programming model relies mainly on the logical structure of the model built with the basis of limited data collected from different European Union institutions and if the model is capable to represent both the use of land and the total production with the existing varieties restricting the values of trade activities. The model will also be validated by comparing the evolution of apples in cold store.

4.8.1 Representing the current situation

The first stage in running the model was the representation of the current situation. Initially no new technical coefficients relating to the new variety were included, thus, the model should replicate the current situation of the 1994 year. The model was run taking into account the existing varieties only. Therefore, the results obtained represent the current[26] apple industry, in terms of land use by variety, European Union income, EIQ units, total labour used, total imports, and exports.

[26] 1994

The reason for doing this was, for example, if the deviation from reality, in terms of use of land, is not high, then this means the current situation (reality) is represented by model successfully. Furthermore, it can be assumed that the structure of the model is functioning correctly, indicating that the model is performing well with regard to identifying the current situation. The model was validated only against production and use of land in 1994. Both labour use and EIQ were not taken into account due to it not being possible to get this data.

In addition, the model attempts to simulate the evolution of apple storage (in cold store) during a year. This is an important point, since apples must be stored through the year in order to maintain the market supplied.

Finally, the first run of the model was under a Linear Programming structure and, it was adjusted in stages due to its first outcomes (infeasible). It was necessary to find out the problems and correct them. After this stage, the model became solvable.

4.8.1.1 Constraints for validation

A set of constraints was established in order to validate the model as was mentioned above and as it was suggested by McCarl and Apland (1986). On one hand, the values of imports, exports, apples for industry were fixed using the figures obtained from the different sources for 1994. On the other hand, the constraints on demand for apples were set up by means of a range. In other words, there is a minimum and a maximum of demand, both by month and by apple apple variety. With regard to land use, the model was not constrained at all.

4.8.2 Validation by running the model

4.8.2.1 Validation of the EU apple industry, without new apple variety

Validation of the mathematical model was carried out by comparing the real observations of land use of apple varieties by NUTS-2 regions and by country, with the land use provided by the model outputs when maximising income. At this stage, it was found reasonable not to include the other objectives of labour and EIQ units. Table 4.18 shows that the average differences between the observed and simulated areas for the five countries selected was -7.95%. This indicates that, according to the model, these five EU countries could meet the needs of apples on a production area that is 7.95% smaller than actually observed. Notwithstanding, when the comparison is made between the amount of apples produced, the results are quite different, as shown in Table 4.19. Here, the difference between observed and simulated production of apples becomes smaller, being 3.62%. In this case the model increases apple production and reduces the area. This could be explained because the model selects those varieties and regions with the highest yield and lowest cost of production respectively. On the other hand, these results could also be explained due to the apple prices used in the model.

Finally, the model has shown to be sensitive when the range of apple demand was changed. Also, the model has been tested changing figures related to yield per hectare per variety and cost of production per hectare.

Table 4.18 Comparison of recorded and simulated apple land use

Country	Observed (*) Hectares	Simulated Hectares	Absolute Deviation Hectares	Percentage deviation
Greece	11426.4	12000	-573.6	-4.78
France	63910	55709.79	-8200.21	-12.83
Germany	38321	37587.97	-733.03	-1.91
Italy	80105.23	71605.66	-8499.57	-10.61
Spain	42517.4	40574.38	-1943.02	-4.57
5 EU countries	236280.03	217477.8	-18802.23	-7.95

(*)Source: Prognosfruit 1995. *European Apple and Pear Forecast,* Italy.

Table 4.19 Comparison of recorded and simulated apple production

Country	Recorded (*) tonnes	Simulated Tonnes	Absolute Deviations tonnes	Percentage Deviation
Italy	2145172.0	2274956.3	+129784.3	+6.05
France	1972300.0	1987810.0	+15510	+0.80
Germany	888400.0	914314.0	+25914	+2.90
Spain	821000.0	884965.4	+63965.4	+7.79
Greece	315000.0	302367.3	-12632.7	-4.01
5 EU countries	6141872	6364413	+222541	+3.62

(*) Source: Prognosfruit 1994

4.8.2.2 Simulating the storage

This first run of the model was useful in order to validate the established equations for simulating the storage sub-model. Figure 4.1, 4.2 and Table 4.20 show the changes in the stock of apples into cold storage. The model was validated against the information available related to apple stock at storage. The information collected refers only to France, Germany and the total EU and the figures correspond for seven months of the year. Despite this gap of information the validation was made against these two countries and taking into account the period from September to March. In addition, it was assumed that there would be 0.33 per cent of losses per month. This coefficient was assumed to be the same for all months, as it was not possible to get the real value of rate of losses in storage for any country. Nevertheless, the model allows us to put different coefficients of losses depending on both the month and the kind of cold store , Controlled Atmosphere or Regular Atmosphere.

Despite the lack of information, the deviation between observed and simulated is small. Obviously, the main problem is the rate of losses used in the model. First, because it varies between months and second, because it was use the same for both storage systems. For example, Figure 4.1, 4.2 and Table 4.20 clearly show that during the first three months the model represents the current situation well. However, after this period the model maintains much more apples in storage and therefore, the deviation becomes greater. In order to test changes at the rate of loss level, the model was run increasing the numerical value of this parameter. The following technical coefficients were used: 0.67%, 1% and 2% during January, February and March respectively. The results are presented in Figure 4.1 as this test was carried out only for France. As this Figure shows, the deviation between observed and simulated becomes smaller.

Figure 4.1 Simulating apples storage per month (France)

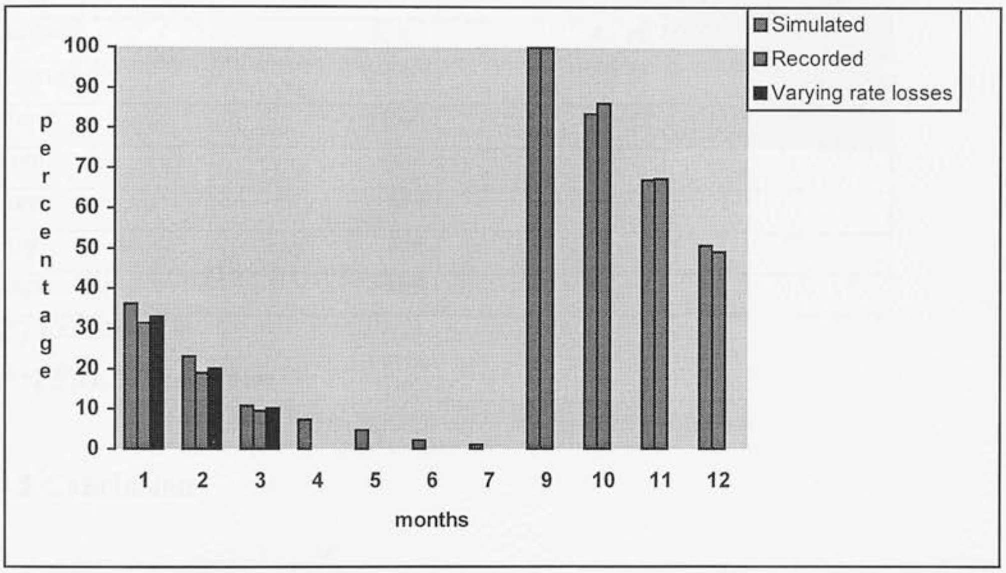


Figure 4.2 Simulating apples storage per month (Germany)

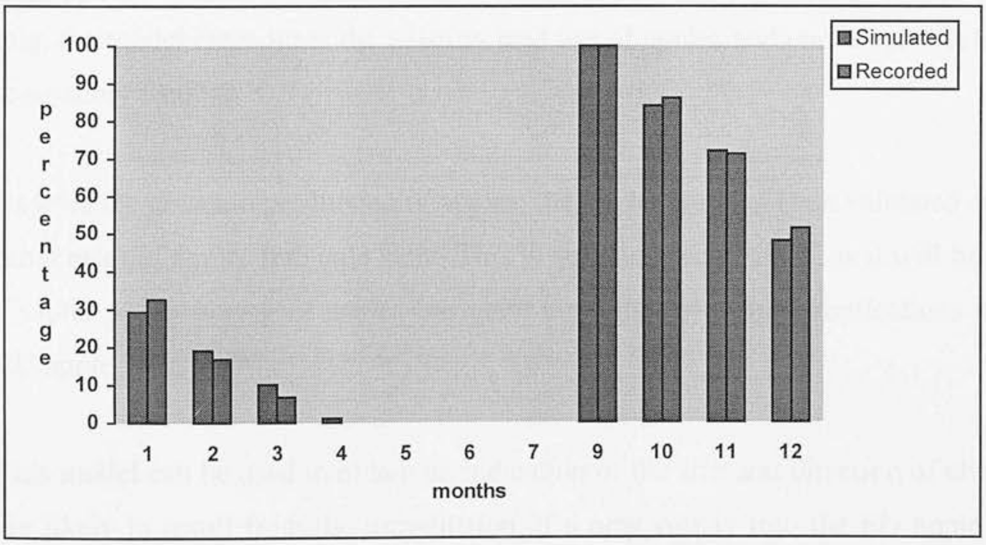


Table 4.20 Simulated and recorded apple storage for EU

Month	Recorded(*)	Simulated(**)	Absolute Deviation
September	100	100	--
October	87.80	83.56	-4.24
November	70.20	68.15	-2.05
December	53.70	53.93	+0.23
January	36.80	43.28	+6.48
February	23.10	33.50	+10.4
March	11.00	24.19	+13.19
April	N/d		
June	N/d		
July	N/d		
September	N/d		

(*) EU 12

(**) Five EU countries

4.9 Conclusion

Naturally, the significant lack of available and reliable data on the functioning of the EU apple industry interferes with the validation of the apple industry model. Despite this, the model reproduces the existing land use of apples and current production levels reasonably well.

Besides the area and production of apples, the model has also been validated against the movement of apples into cold store. This is quite important since, as it will be shown in Chapter 6, the storing of apples has quite important economic implications within the EU apple industry.

This model can be used to obtain an indication of the size and direction of changes that are likely to result from the introduction of a new variety into the EU apple industry.

The model is capable to be used for evaluating the impacts resulting from the introduction of a new apple variety into the EU apple industry.

Chapter 5
Application of the Goal Programming Model: results and discussion

Using the data described above, the Goal Programming model developed for this study needed to be used for simulating specific scenarios. Taking into account the lack of data for the new apple variety, it was necessary to explore a number of possible scenarios. This chapter presents and analyses the GP model run results of such scenarios. It is important to highlight that the characteristics of the new apple variety have been "guesstimated" since it was not possible to get sufficient information about it. Therefore, the results presented in this chapter are referred to as no real new apple variety. Consequently, the social, economic and environmental impacts presented here are only hypothetical. Despite this, the GP model was found to be a useful tool in order to explore in depth possible impacts after introducing a new apple variety into the EU apple industry. The Chapter begins with a brief description of the scenarios in section 5.1 followed by results of model runs.

5.1 Scenarios description

This section describes the scenarios under which the GP model was run. By changing some of the parameters and weights attached to each undesired deviational variable, the GP model of the EU apple industry can be used to simulate specific scenarios for the new apple variety. Clearly, a large potential number of scenarios could be explored, but the following scenarios have been selected with intent to explore some specific circumstances.

5.1.1 Characteristic of the new variety

As stated before, it was necessary to describe a hypothetical new apple variety. Table 5.1 shows the technical coefficients used for running the GP model. It was assumed that the new variety would perform differently depending mainly on the EU country where it will be cultivated. The values selected for the new variety (yield per hectare, labour usage and cost of production) correspond to an average of the existing varieties.

Table 5.1 Performance of the new apple variety

Country	Yield Tonne/ha	Total EIQ unit/ha	Total Labour use Hours/ha	Cost ECU/ha	Monthly Rate losses in storage %
Greece	26.00	1905.92	817.00	1924.98	0.33
France	31.08	8357.38	803.05	3082.42	0.33
Italy	36.70	4595.04	586.00	4392.08	0.33
Spain	28.01	5432.00	545.00	3180.00	0.33
Germany	24.12	643.15	505.00	3500.00	0.33

Source: Adapted from Confcooperative Unione di Ravenna; E.S.A.T. Trento; Centro Operativo Ortofruticolo Ferrara (1992);Universita di Torino (1984);C.T.I.F.L. (1990;1995);CEMAGREF (1994);ZMP (1994); Universidad Politecnica de La Almunia; Costa Brava co-coperative;University of Thessaloniki.

5.1.2 Penalty Weights

The Weighted Goal Programming (WGP) algorithm selected for this study requires that weights be assigned to the goals. Such weights allow us to penalise undesirable deviations from goals with different degrees of severity. Penalty weights of 1, 3, 5, 6 and 10 were arbitrarily selected, used under all twenty-four possible permutations or penalty weight scenarios (see Table 5.2). Therefore, different combination of weights generate different scenarios accounting for potential preferences of decision-makers.

5.1.3 Economic scenarios

The model was run simulating three different price levels for the new variety (see Table 5.2).

1) P1 assumes that the price for the new variety will be the lowest registered for the existing apple varieties.
2) P2 corresponds to an average apple price for the existing apple varieties.
3) P3 simulates a situation where the new apple variety would reach the highest price that is paid for the existing apple varieties.

With regards to the cost of production of new apple variety, the model was run under only one possible scenario. The technical coefficient used in this case was the average cost of production of the existing varieties. There is no reason for thinking that the new variety will decrease the cost of production, except the decrease in cost due to the reduction of pesticide usage (specifically fungicides). Another cause of reduction costs could be as a result of a lower labour usage. Notwithstanding, these parameters were taken into account in a separate part of the matrix as explained in chapter 3.

5.1.4 Environmental scenarios

Special attention was paid on the environmental aspects of the GP model. As explained before, the EIQ was split into its three individual components, i.e. field workers, consumers and environment. Consequently, several different scenarios were generated. Firstly, the model was run weighting with the same value the three pollution goals (G2, G3 and G4 see chapter 3), as is shown in Table 5.2. Secondly, the model was run changing the penalty weight on one of the pollution goal (for example, G2= producer) and keeping the rest of the goals unchanged with a penalty weight of 1 (see Table 5.2, R6 to R21). These runs were carried out in order to observe how the GP model selects hectares under new apple variety when the DM's desires are different by each component of the EIQ formula.

Table 5.2 Weights attached to each undesired deviational variables

Goal Description	Goal Weights Level for Run																							
Runs	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14	R15	R16	R17	R18	R19	R20	R21	R22	R23	R24
Economic	New Variety P 1				New Variety P 2				New Variety P 3															
Income (ECUs)	1	3	6	10	1	3	6	10	1	3	6	10	1	1	1	1	1	1	1	1	1	1	1	1
Environmental																								
EIQ Field Workers	1	1	1	1	1	1	1	1	1	1	1	1	3	6	10	5	10	1	1	1	1	1	1	1
EIQ Consumers	1	1	1	1	1	1	1	1	1	1	1	1	3	6	10	1	1	5	10	1	1	1	1	1
EIQ Environment	1	1	1	1	1	1	1	1	1	1	1	1	3	6	10	1	1	1	1	5	10	1	1	1
Social																								
Labour (Hours)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	6	10

R1...R24 = Model Runs

New Variety P1= Lowest apple price

New Variety P2= Average apple price

New Variety P3= Highest apple price

5.1.5 Social scenarios

Like economic and environmental aspects, changes in labour were explored by mean of penalty weights of 1, 3, 6 and 10. Again, the demand for labour by the new apple variety comes from an average of the existing apple varieties.

5.2 Results of the Goal Programming model

The output from the GP model provided a significant amount of information, not all of it useful in the decision making process. The results presented here relate to experimentation with the GP model into the effect of varying the weights attached to each undesired deviational variable in the objective function. The results include the amount of hectares (new variety) that the model adopts under different scenarios and the maximum achievable goal levels, (i.e. total ECUs, total EIQ units and total hours of labour).

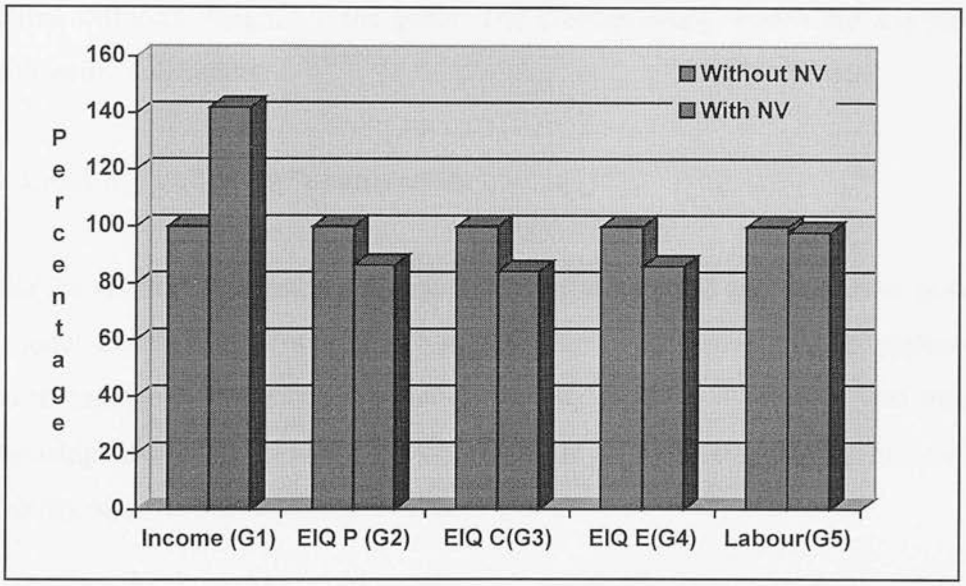
The results presented in this section correspond to the five European Union (EU5) countries selected, i.e. Italy, France, Germany, Spain and Greece and, they will be presented and discussed from the economics, social and environmental points of view.

5.2.1 Introducing a new apple variety

The first scenario to explore concerns the impact which might occur following the introduction of the new variety with the characteristics described above. This means to look at the differences between the solution obtained without the new variety and the solution obtained including the new apple variety in the EU5 apple industry. These model runs were carried out giving the same relative importance to each goal. All the goals were considered simultaneously in a composite objective function which minimises the sum of all the deviation among the goals and their aspiration levels (R1, weights = 1 in Table 5.2).

As Figure 5.1 shows, the total EU5 income improves by approximately 40% when the new variety becomes available in the EU5 countries. Such income increases can be explained by the technical coefficients used for the new variety. For instance, the new variety has better performance when compared with some of the existing varieties, since the numerical values used in the model correspond to an average of the existing varieties. Thus, the model increases the number of hectares under new apple variety to the detriment of the hectares under existing varieties.

Figure 5.1 Effects of introducing a new apple variety



With regards to the EIQ, there was a reduction of approximately 20% when the new variety is available into the EU5 apple industry. Again, this is explained because the EIQ value used for the new variety is 40% lower than the existing varieties. Naturally, such reduction of 40% was arbitrarily selected. Despite the reduction of 40% in the EIQ value, the reduction is reflected in only 14% on the total EIQ for the EU5 apple industry. This is explained because it is seen that only 65% of the available land in the EU5 came into the plan for growing apples with the new apple variety. The remaining 35% are cultivated with the existing varieties.

Finally, labour shows the smaller variation regarding the introduction of the new apple variety. Approximately labour use is reduced by only 2% when the new variety becomes available. In this particular case, the model was designed to penalise both under- and over-achievement of the labour goal (i.e. the goal was to maintain current labour use).

According to these results, it is possible to conclude that there is no conflict between the attributes selected for the analysis, as Figure 5.1 shows, the EU5 income increased, the EIQ value dropped and labour almost completely achieved the aspiration level established. Nevertheless, different solutions can be achieved by attaching different weights to the goals. The corresponding results are analysed in the following sub-section.

5.2.2 Land use under apple cultivation

Unlike the results presented above, the following results are going to show how the GP model distributes the available hectares when different relative importance is given to each goal. Therefore, the model was used in order to gain insights into the relationships that exists between social, economic and environmental goals, and the sensitivity of the model to changes in those goals.

As mentioned before, constraints related to land use activities were established. The model was constrained in such a way that at least 30 per cent of the current land under apple production must be occupied by the existing apple varieties. Consequently, the remaining 70 per cent of land would be able to be cultivated with the new apple variety. Despite this arbitrary value, it was assumed that producers who would benefit from a new technology (new apple variety), often require a considerable amount of extension provision before they adopt it. On the other hand, new technologies often carry a different risk from existing technologies. Thus the new technology is likely to find acceptance with the richer farmers, who can carry these risks. Therefore, a variable period exists between a new technoiogy being generated and being effectively adopted by the farmers. This point would justify the land use constraint established.

Figures 5.2 and 5.3 show clearly the inter-relationship that exists between income-pollution-labour and the land use of new variety. When the highest importance is given to income (weight=10), the model selects the lowest amount of hectares to be cultivated with the new apple variety. On the contrary, when the maximum weight is attached to the environmental attribute (10), the land use under new apple variety becomes the highest. According to these results it is possible to conclude that conflict does exist between income and pollution reduction. When the maximum weight is attached to income, the absolute value of hectares cultivated using the new variety is 70,450.97 (29.82% of the total land), while this value reaches 115,183.18 (48.77%) when the relative importance is changed in favour to pollution reduction. This effect could be explained because of the technical coefficient used for the new variety. One possibility would have been to run the GP model with a smaller EIQ value for the new variety. Nevertheless, such an alternative was rejected because the new variety will be only resistant to *Mildew* and *Scab* diseases. Thus, the EIQ of the new variety would not be too much lower. However, the Chapter 6 presents a sensitivity analysis where the model was tested by changing the hypothetical EIQ value for the new apple variety.

Unlike income, labour and pollution attributes do not seem to be in conflict, since the pattern of the existing and new varieties is quite similar. When labour is attached with the maximum importance (10), the resulting share of land under new variety is 48.53%. This percentage is practically the same when pollution is weighted with the maximum value selected (see Figure 5.3 C and D).

Figure 5.2 Land use of new and existing apple variety by different scenarios.

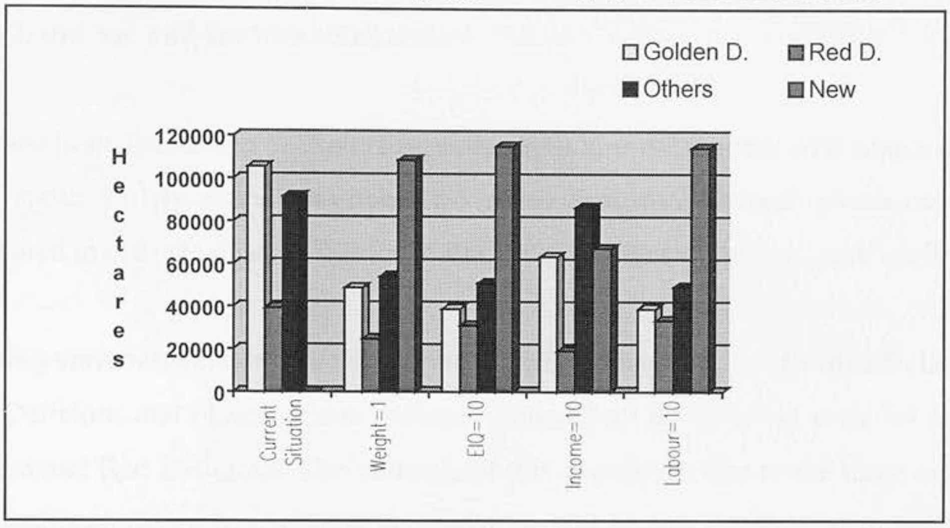
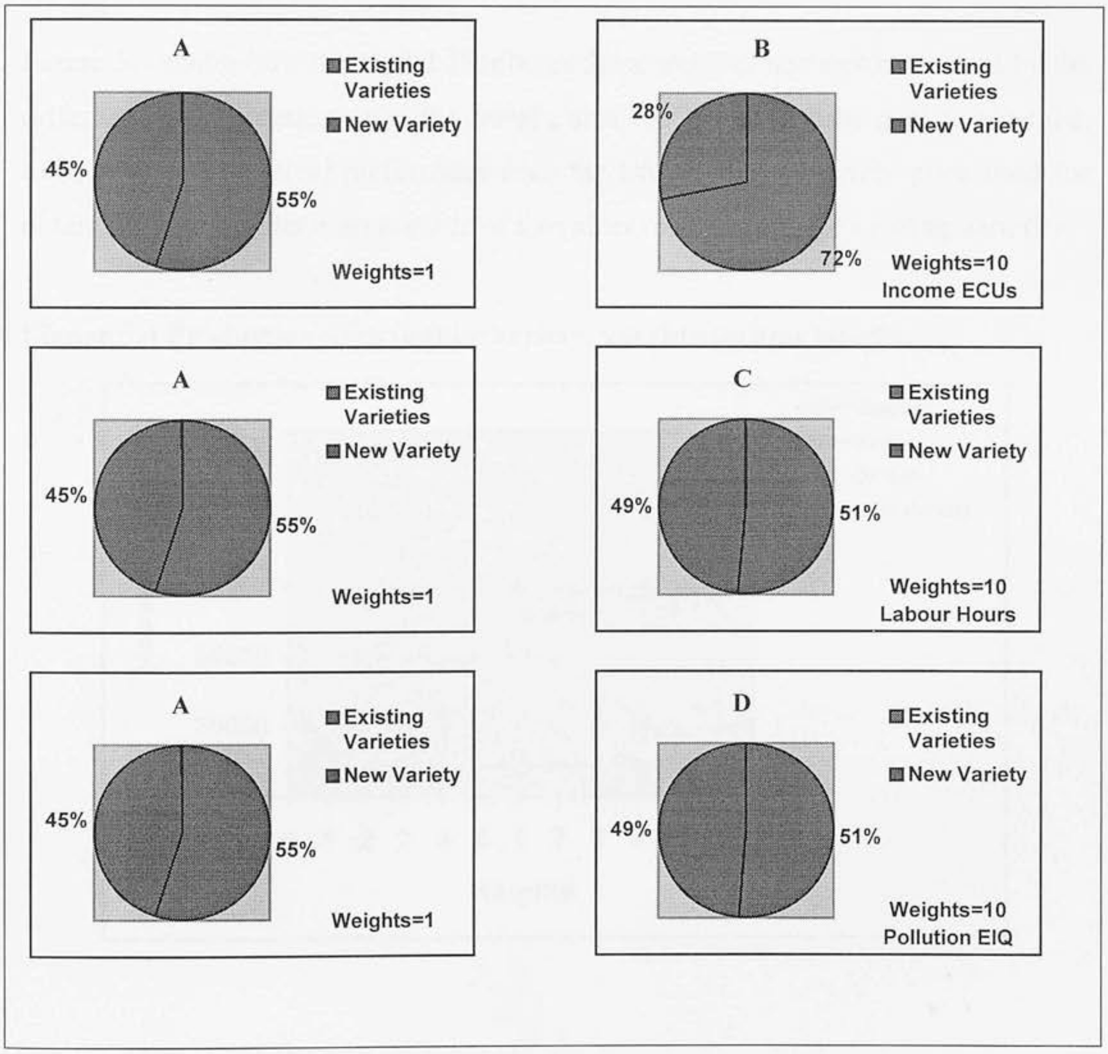


Figure 5.3 New variety. Use of land by attribute



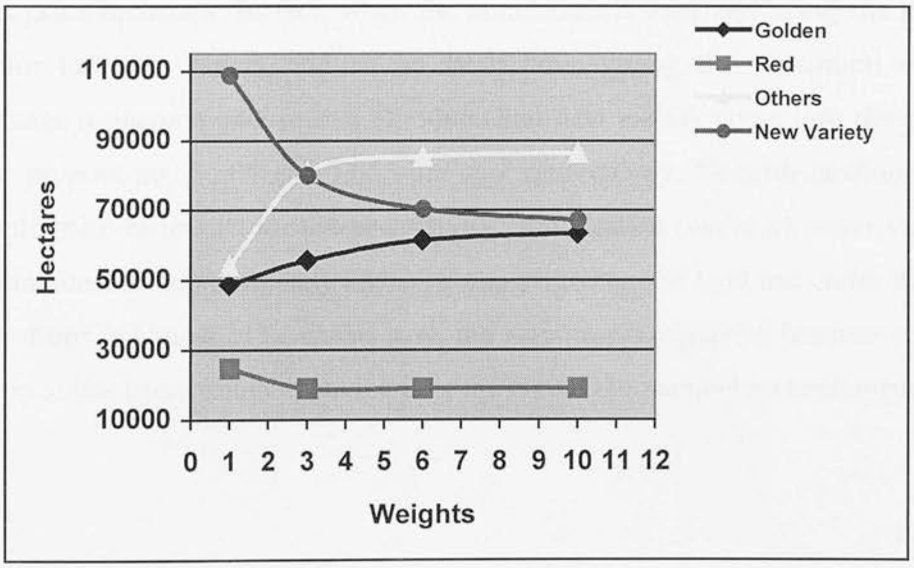
5.2.3 Land use and Income scenarios

It seems to be interesting to explore in more depth how the number of hectares of the new apple variety come into the EU5 apple industry. Several scenarios were simulated in order to observe this issue attaching different weights to each attribute.

Existing varieties were grouped into three different categories, i.e. Golden Delicious, Red Delicious and others, where "others" included all the existing varieties except Golden and Red Delicious. The rationale of this decision is due to the large amount of existing varieties in each country and it would be too difficult to manage the information obtained.

Figure 5.4 shows how the model distributes the amount of hectares cultivated by the different apple varieties when the weight attached to the income goal is changed, thus, reflecting different preferences from the DM. The new variety price used for obtaining these results is an average of the prices recorded for the existing varieties.

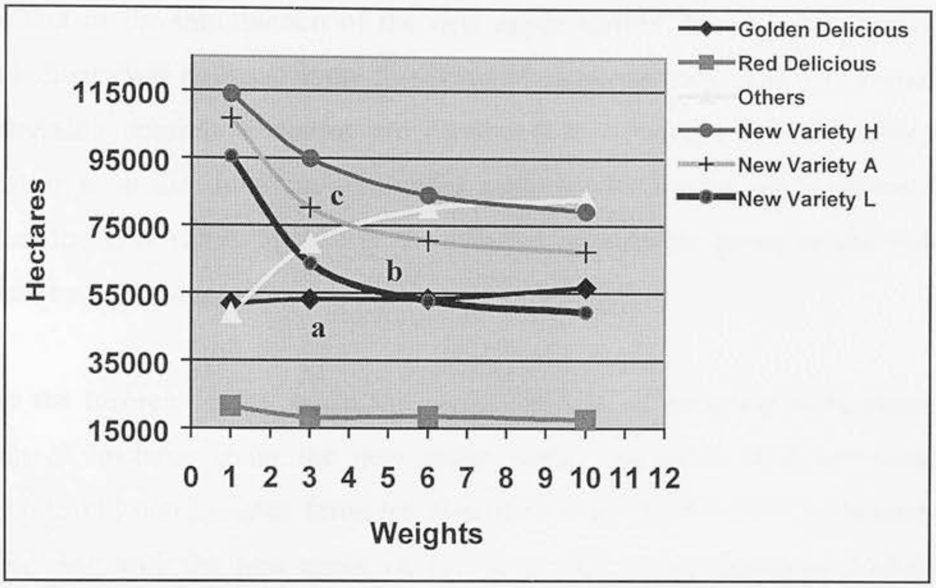
Figure 5.4 Production area (ha) by variety, varying income weight.



It is important to stress that both "others" and the "new" varieties are most sensitive when the relative importance is changed. Figure 5.4 also shows that the variation registered on the Golden and Red Delicious is not pronounced. The increase of land use recorded for "others" varieties could be explained because of the technical coefficients used in the matrix. Some varieties, other than Golden and Red Delicious, show a very low cost of production per tonne. Thus, when the relative importance is increased toward income, the GP model increases the use of other varieties and at the same time reduces the number of hectares under new apple variety.

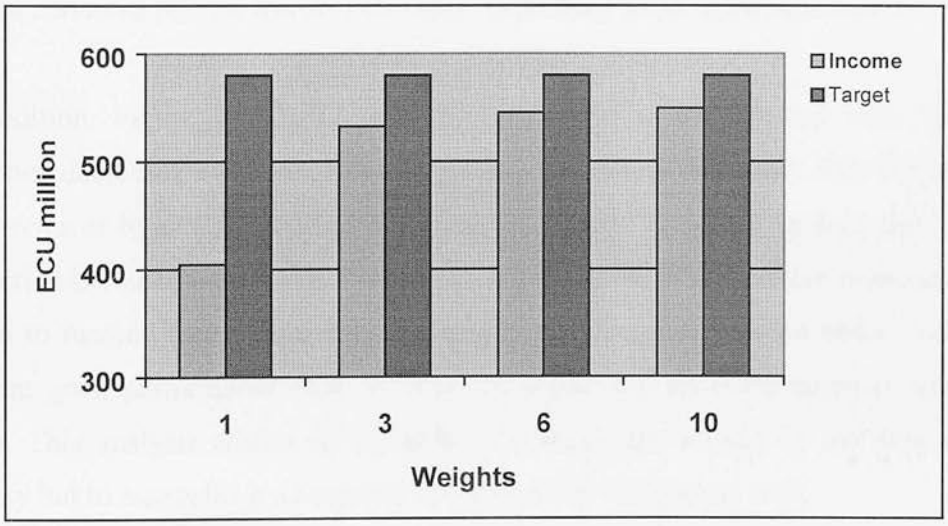
As stated above, since there was not sufficient information available about the market price for the new variety, the model was run under a set of possible scenarios in order to observe the effects of varying this parameter. Twelve runs of the GP model were therefore carried out varying the new variety price levels and the weights attached to desired deviational variables. These scenarios are shown in Table 5.2 (Run 1 to 12). The weights were varied in an effort to reflect the decision-maker's preferences with regard to the income attribute. Farmers for instance, would want to maximise income. Figure 5.5 shows the effects on the land use of the new variety. As expected, the attractiveness of the new variety will increase when its market price increases. In fact, when the simulation is executed using the highest price for the new variety and at the same time, giving the maximum relative importance to income goal (curve ***c***), others and new variety come into the plan in similar proportions, 35.04 and 33.53 per cent respectively. Notwithstanding, when the apple price estimated for the new variety is the lowest (curve ***a***), other varieties are maintained at approximately 35%, but the percentage of land use under the new variety drops to almost 21%. In this case, the variation is explained because only the apple price has been changed, having kept the rest of the parameters unchanged.

Figure 5.5 Production area (ha) by variety, varying income weight and market price of the new variety. (High=H, Average=A, Low=L)



The effect of different model runs in the EU5 apple industry on the weights given to the achievement of income goal (1, 3, 6 and 10) is depicted in Figure 5.6. The income goal is better achieved (+30%) when the relative importance to this goal is increased from 1 to 3. Nevertheless, when this value is increased to 6, the marginal improvement of the income goal is only in 2.4%, with the increase being even lower when the penalty weight is increased to 10.

Figure 5.6 Level of goal achievement, EU5 income



5.2.4 Environmental impact

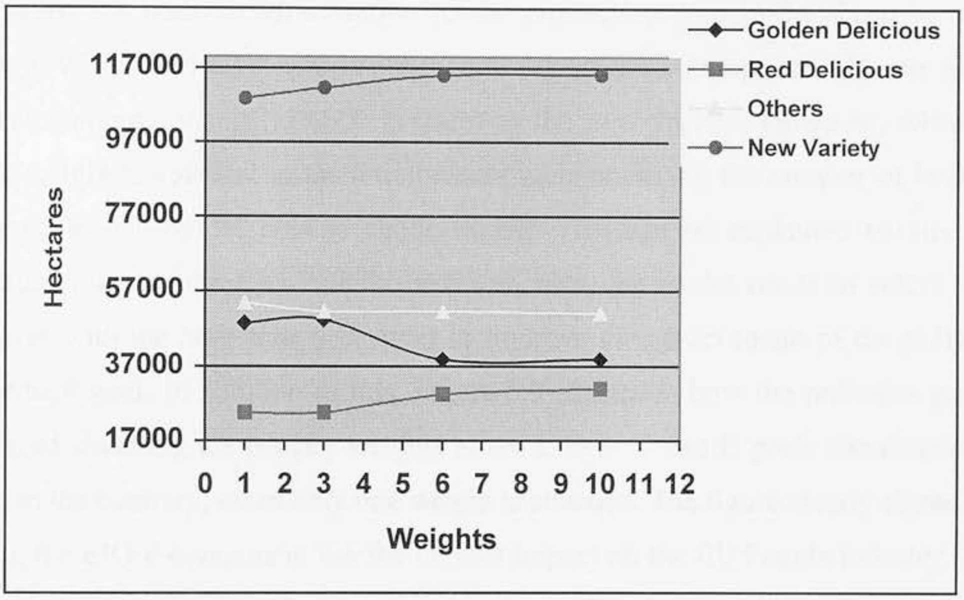
The effect of the introduction of the new apple variety into the European Union apple industry was assessed at the five selected countries level. The EIQ values used for assessing possible scenarios are presented in Appendix 3.1. It seems to be interesting to analise how the area under apple production by apple variety varies whether the DM wants to modify the relative importance given to the pollution attribute by increasing or decreasing the weight attached.

Unlike the income results, when the penalty weight of pollution is increased, the amount of hectares under the new apple variety increases from approximately 108,000 to 115,000 hectares, however, almost 50% of the total EU5 apple land come into the plan with the new apple variety when this variety becomes available. In addition, Red Delicious increases from 25,000 to 31,000 hectares while Golden Delicious decreases from approximately 48,000 to 38,000 hectares (see Figure 5.7).

The first conclusion that follows from Figure 5.7 is that Red Delicious would be a more "environmentally friendly" apple variety than Golden Delicious. Since the production area of Red Delicious is increased by approximately 24% when the relative importance is augmented in favour of pollution abatement. It is important to highlight that most of the changes are produced when penalty weights vary between 1 and 6. Since, the curve becomes flat when the weight ranges between 6 and 10, it can be deducted that the lowest EIQ value is reached when the weight is 6.

In addition, Figure 5.7 shows how the production area cultivated with "other" varieties decreases when the value of penalty weights is increased. The GP model only reduces by 6% the land use allocated to "other" varieties. In fact, this slight reduction is consistent with the fluctuation registered when the relative importance is given to income (see Figure 5.4). Therefore, the varieties grouped under "others" present good performance from both an economic and an environmental point of view. This analysis allows us not only to evaluate the impact of the new apple variety but to assess the performance of the existing varieties as well.

Figure 5.7 Production area (ha) by variety, varying EIQ weights.



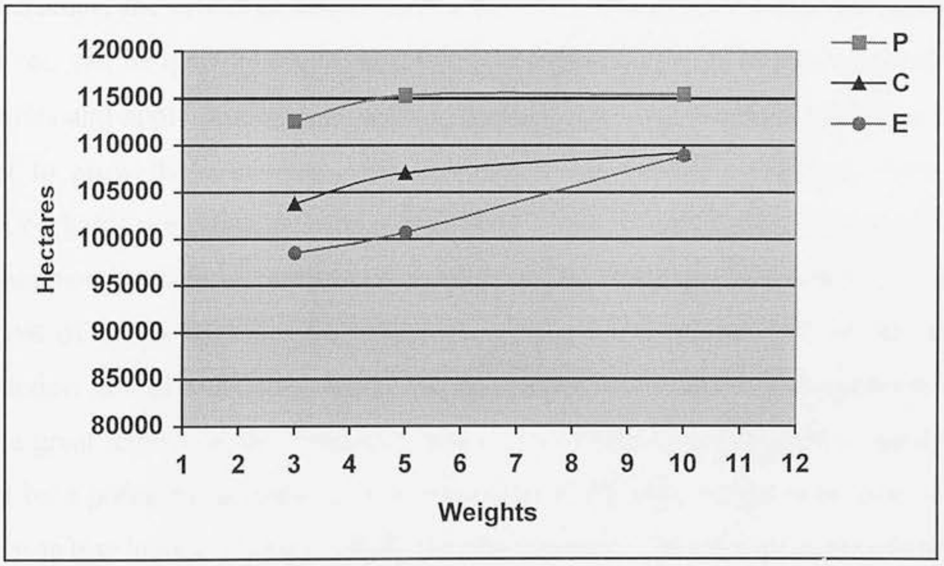
As mentioned in chapter 3, the EIQ value was split into its three components in order to be integrated to the GP model. Consequently, in order to explore the effect of weighting pollution by each component of the EIQ formula, the following scenarios were established;

- weights 3, 5 and 10 attached to field workers component (G2), consumer and environment components at 1,
- weights 3, 5 and 10 attached to consumers component (G3), field workers and environment components at 1 and,
- weights 3, 5 and 10 attached to environment component (G4), consumer and field workers components at 1.

The GP model was designed to allow the DM to test the new apple variety by each component of the Kovach *et al* (1992) formula (see page 71). For instance, a new apple variety could have a lower EIQ value than the existing varieties but only in one of the EIQ formula components, hence the resulting impact as a result, would be different.

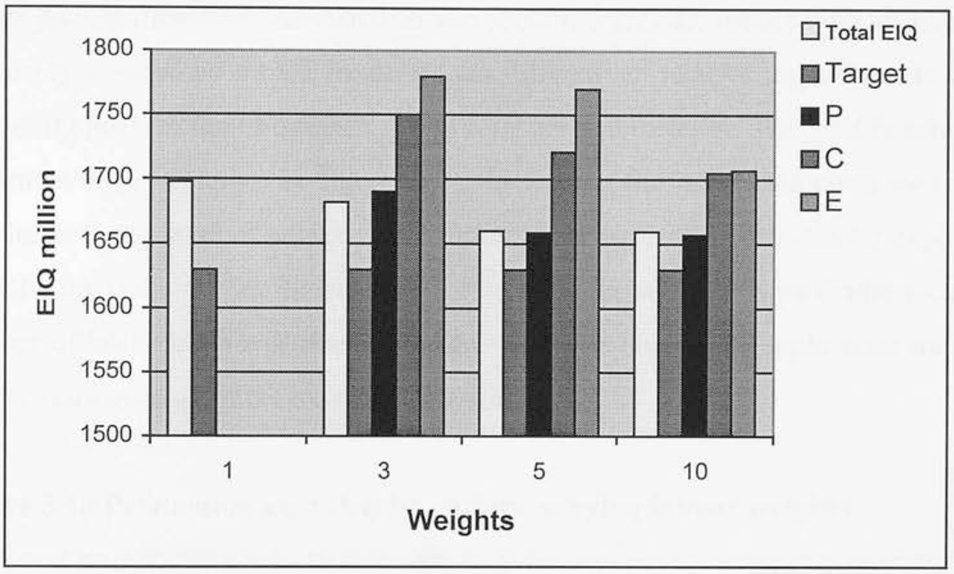
When the penalty weight is modified only on one of the EIQ component, the weights on the remaining EIQ components stayed unchanged (w=1). The results summarised in Figure 5.8 refer to the variation in the production area under the new apple variety. When the weight of 3 is attached to the producer component (P), the model allocates approximately 112,000 hectares to the new variety. However, when the same weight is attached to the environment component (E) the number of hectares selected by the model falls to about 98,000. This can be explained because the absolute value of the EIQ P is the smallest, thus, the model needs to select more hectares with the new variety in order to improve the achievement of the pollution abatement goal. In addition to this, Figure 5.9 illustrates how the pollution goal is achieved attaching the penalty weights to the EIQ P, C and E goals simultaneously and, on the contrary, when only one weight is attached. The figure clearly shows that again, the EIQ P component has the highest impact on the EU5 apple industry. This is quite important, since it means that if the DM interest is directed towards the reduction of only one of the component values, the model can deal with this.

5.8 Production area (ha) of new variety, varying EIQ weights by EIQ components



P= EIQ Field workers component
C= EIQ Consumers component
E= EIQ Environment component

Figure 5.9 Level of goal achievement, EU5 EIQ values.



5.2.5 Social impact

One of the goals in the EU5 apple industry is the maintenance of employment. As a consequence, the model penalises both under- and over-achievement. This decision, however, can be questioned. In fact, undoubtedly there are differences between EU countries and apple production systems. For instance, Greek farmers perhaps would prefer to grow those varieties with the lowest requirement of labour, since their apple orchards are managed with a high family labour component. The availability of manpower in each EU country is another variable affecting this decision. Further, the cost of labour also has an important impact, since almost 50% of the cost of production is attributable to labour. Thus, a small reduction in this parameter will have a great impact on the economic results (see chapter 6). On the other hand, there could be a potential increase in unemployment if the new variety was adopted and there was less labour demand in the pesticide industry. Despite these considerations, the model was designed in order to maintain the same level of labour registered in the base year, as being the optimal situation to maintain.

Three different runs (see Table 5.2 R 22 to 24) were carried out varying the relative importance given to the social goal. Figure 5.10 illustrates how the use of land under the different apple varieties change when the relative importance attached to the labour goal is increased. As stated in sub-section 5.2.2, the distribution of hectares by variety selected by the GP model do not differ when relative importance is given to the EIQ goal. In fact, Figures 5. 7 and 5.10 are quite similar. The goal is achieved by almost 99% as shown by Figure 5.11. Increasing the relative importance to this goal leads to the level of achievement almost reaching 100%. This can be explained again by the technical coefficient used for the new variety. In this particular case, the number of hours of labour needed for growing one hectare of apple with the new variety is an average of the existing varieties.

Figure 5.10 Production area (ha) by variety, varying labour weights

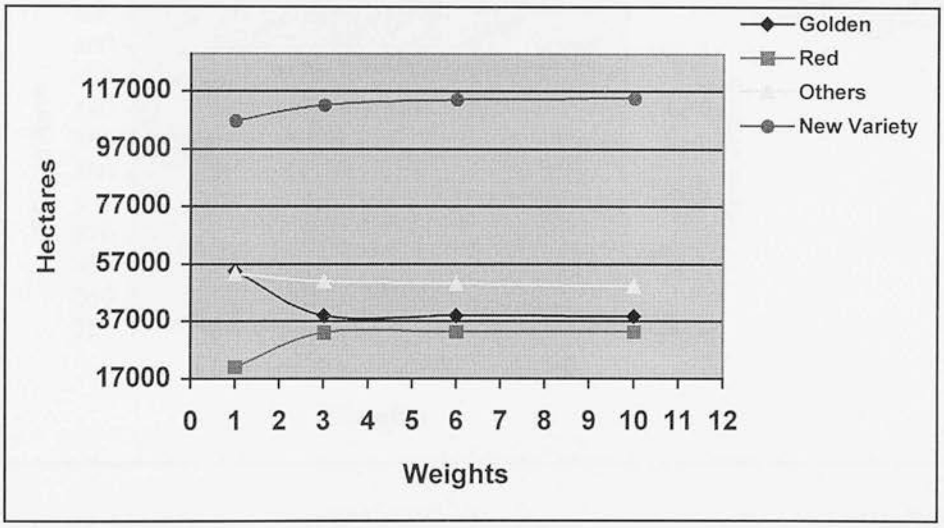
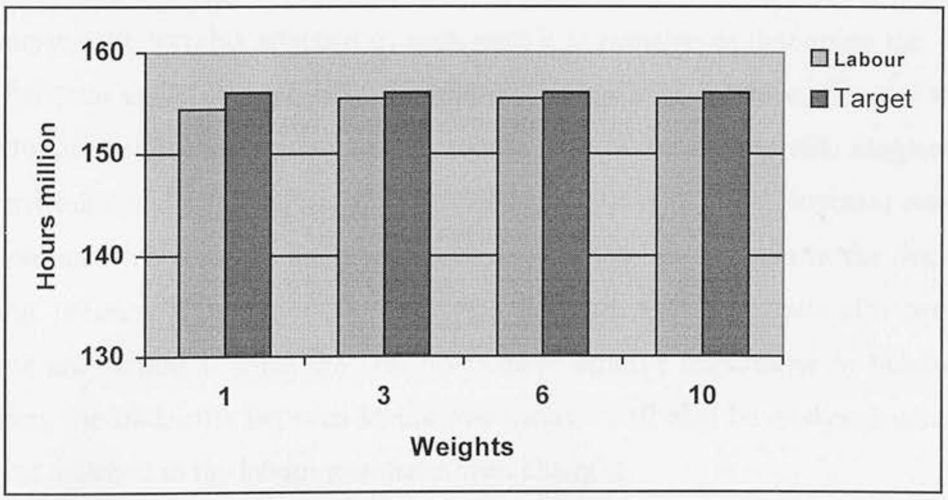
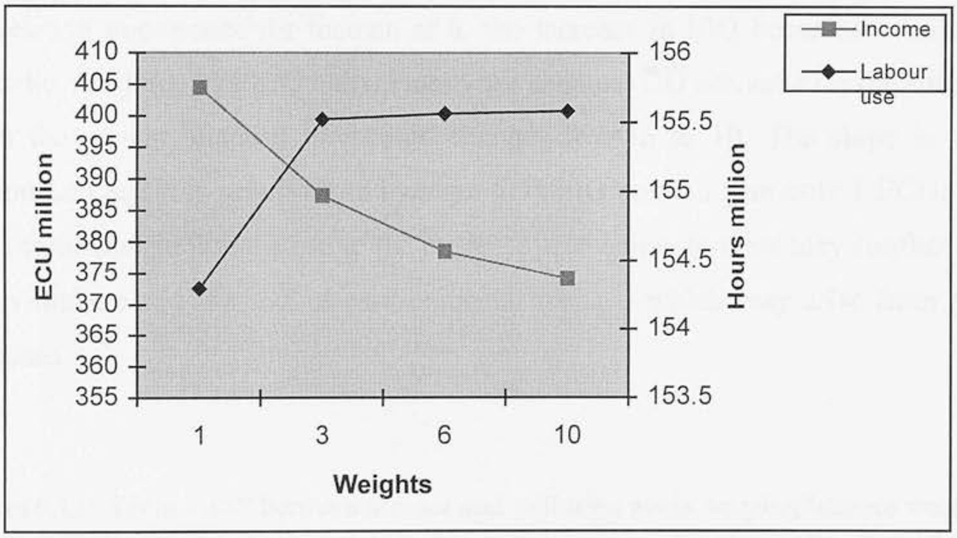


Figure 5.11Level of goal achievement. EU5 labour



However, by comparing income and labour goals, when an increase in the penalty weight value is attached to the labour goal there is an appreciable fall in the income goal as is depicted in Figure 5.12. In this case, the model had to increase the number of hectares cultivated with those apple varieties with a greater use of labour in order to improve the goal achievement. As a result, total value of income became smaller. The total EU5 income is quite sensitive to changes in the labour preferences. As stated before, this can be explained due to the high proportion of labour costs within the total cost of apple production (see Appendix 1.2).

Figure 5.12 Income and labour weighting labour goal



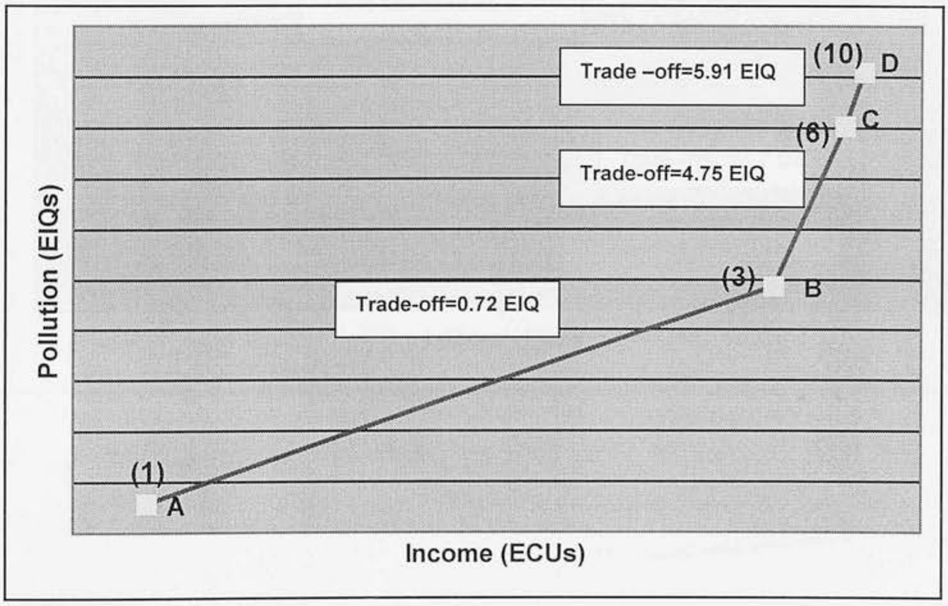
5.3 The trade-offs between goals

By varying the weights attached to each goal it is possible to determine the trade-offs between goals or even between interest groups. For instance, farmers would want to increase income, policy makers would want to reduce pesticide usage due to the environmental implications of this. Further, the level of unemployment can be a problem and this could be another impact to be taken into account in the decision-making process. This sub-section presents the corresponding trade-offs between income and pollution when the DM gives more relative importance to income. In addition, the trade-offs between labour and income will also be analysed when the weights attached to the labour goal have been changed.

5.3.1 Trade-offs between Income and EIQ

The trade-offs between income and EIQ which occur when varying the weights attached to the income goal are presented in Figure 5.13. Points A,B,C and D represent the results of the model when weights of 1, 3, 6 and 10 were attached to the income goal. For instance, the slope of segment $\overline{AB}$ is 0.72. This value means that when the DM increases the relative importance to income goal from 1to 3 (whilst keeping the EIQ weight at 1), improving the total EU5 income by 1 ECU would require an increase of 0.72 EIQ units. Nevertheless, when the DM weights the relative importance for income at 6, the increase in EIQ becomes even more dramatic, reaching 4.75 EIQ units. Finally the segment $\overline{CD}$ accounts for the situation when the weight attached to income changes from 6 to 10. The slope is more pronounced and it is necessary to increase 5.91 EIQ units to gain only 1 ECU. This gives some insight into the use of the model to assess how farmers may conflict with policy-makers and the sort of environmental damage which may arise from price increases.

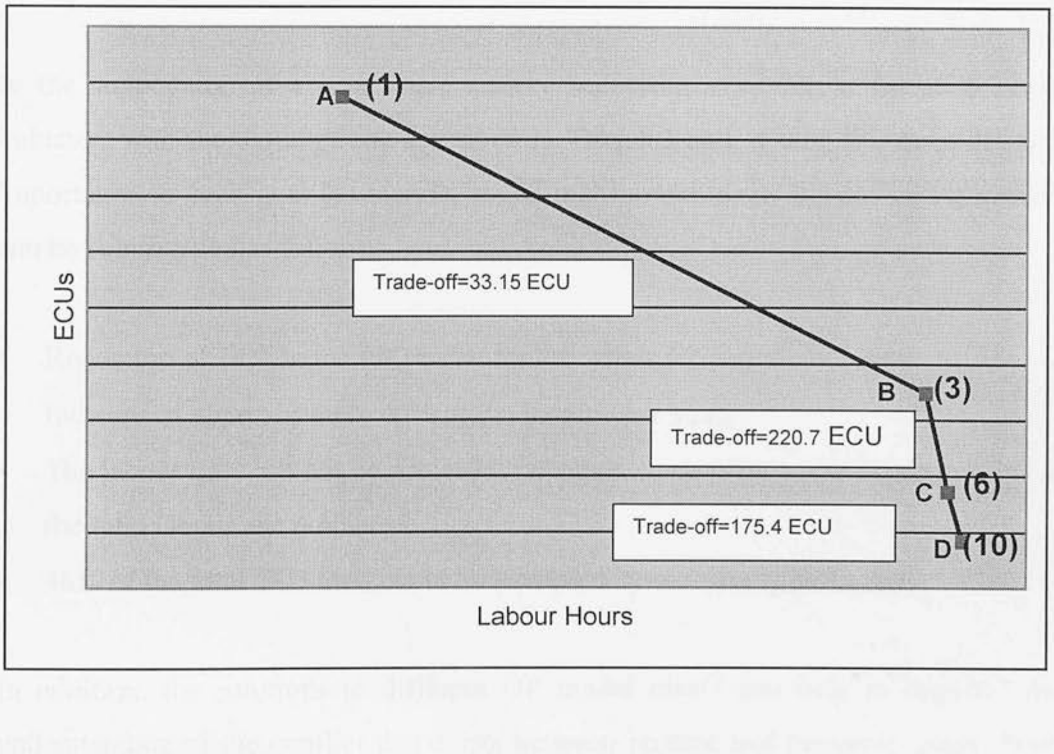
Figure 5.13 "Trade-offs" between income and pollution goals, varying income weights



5.3.2 Trade-offs between Income and Labour

In the same way, the trade-offs between total EU5 income and total labour use are depicted in Figure 5.14. Here, the points A, B, C, and D again represent the different weights of 1, 3, 6, and 10 attached to the labour. For instance, the slope of segment $\overline{AB}$ is 33.15 which means that to improve the achievement of labour goal by 1 hour requires a reduction of 33.15 ECU in the EU5 income. In this case, the GP model not only increases the amount of labour but the model changes the production area cultivated with the varieties available as explained in sub-section 5.3.3. When the weights attached to the labour goal is greater than 3, the reduction in the total income is even more pronounced, rising to 220 ECU per hour of labour included in the plan.

Figure 5.14 "Trade-offs" between income and labour goals, varying labour weights



5.4 Conclusion

The representation of a real world problem using a WGP framework presents all the real world problems that normally occur in the impact assessment process. In this particular case, the major problem was the lack of data relating to the characteristics of the new apple variety. Further, the model was designed to represent apple trade activities on a monthly basis even though a few EU countries supplied us with this information.

The effects of changing the weights attached to each goal for the EU5 apple industry have been discussed. Running the GP model suggests that introducing a new disease resistant apple variety into the EU5 apple industry satisfied an increase in income, a reduction of EIQ and maintenance of the labour usage for the base year of 1994. In fact, there certainly is a possibility of increasing income by introducing a new apple variety. At the same time, it is clear that a reduction of EIQ units will occur by cultivating such new variety.

In the supposition of a new apple variety becoming available to the EU5 apple industry, with the assumptions described in Table5.1 and, giving the same relative importance to each goal (economic, social and environment) the modelling results can be summarised as follows;

- Reduction of 14% in the EIQ value for the whole EU5 apple industry.
- Increase of approximately 40% of the income per year.
- The labour goal can not be achieved, however, there is only a reduction of 2% in the total labour use predicted.
- 46% of the total EU5 land could be occupied by the new apple variety.

In addition, the solutions to different GP model runs[27] can help to improve the understanding of the conflict that exists between income and pesticide usage. Such results are a further justification for using the MCDM framework in modelling the EU apple industry. The full results are included in Appendix 5.1.

[27] By varying the relative importance given to each goal

The apple yield estimates used in this model are average figures achievable in the base year of 1994. In a practical situation, the yield of different apple varieties does not remain the same every year because of the variation in climatic and other factors (e.g. pest and diseases). One of the possible solutions is to re-run the GP model several times with alternative yield assumptions. This is partially explored in chapter 6. However, simulations only highlight the changes for the new apple variety. Like yield, the potential price for the new apple variety is another unknown parameter.

The GP model was set up for a period of one year only, with fixed resources and well-defined limited activities. Nevertheless, the reality is that the whole EU apple industry is in a dynamic state.

The modelling approach has served a useful purpose in integrating social, economic and environmental parameters in order to determine how land resources should be utilised to meet specific goals and in determining the effects and trade-offs that would occur under different weights scenarios.

Taking into account the shortage of data mentioned and these shortcomings, the next chapter will present a comprehensive sensitivity analysis varying the numerical values for some of the parameters mentioned.

Chapter 6
Sensitivity Analysis of Assumptions

6.1 Introduction

This chapter discusses how changes in certain parameters of the new variety of apple would affect the GP model outputs. As detailed in Chapter 3 a set of assumptions were made due to the lack of information related to the new apple variety, i.e. yield per hectare, cost of production, usage of pesticides, labour demand, losses in storage, EIQ values, etc.. Sensitivity analysis with mathematical models is specifically suited to testing the validity of such assumptions.

Sensitivity analysis is defined by Dent and Blackie (1979) as;

> *"a procedure carried out on the completed and, at least partly, validated model which involves exploring the operation and performance of the model"*

The value of a parameter may be changed and the model output analysed to determine whether or not the changed parameter values are of material consequence.

A sensitive parameter is one which causes a major change in model output, and the model is said to be sensitive to such a parameter (Dent and Blackie, 1979). Therefore, it is important to see for which parameters a small relative change in the value leads to a relatively large change in either the value of the solution or the composition of the solution. Sensitivity analysis helps to determine the impact of the uncertain new variety estimates values on the results given by the GP model. Moreover, when multiple objectives are included, like in this study, the weights on goals can also be varied to explore the possible implications between goal and results.

A sensitivity analysis is carried out by means of successive runs of the model under identical environmental conditions. When a specific parameter was being tested, the remaining parameters were fixed with the corresponding average value observed in the existing apple varieties. The analysis involves varying the numerical value of a parameter and observing the degree of changes to the solution (Gittinger, 1982). Therefore, it is possible to see the effects to the overall apple industry in terms of economic, social and environmental aspects. In this particular case, the GP model has been run 53 times (R1 to R53), using different combinations of the new variety technical coefficients. The GP model outputs will be discussed in the following sub-sections.

Since the model is basically a repeated structure for all 5 EU countries, only one sub-matrix for one country was selected for this analysis: Italy. Several reasons influenced the choice of this alternative. In the first instance, Italy is the most important apple producer among Member States. Italy produces approximately 30% of the total EU production. In the second instance, almost 25% of the total EU apple land is located in this country. Therefore, it is possible to assume that a sensitivity analysis carried out on the basis of Italian figures could be extrapolated to the rest of the Members States. Last but not least, constraints of time affected this study. Consequently, by running the analysis on one country, a considerable amount of time was therefore saved.

The parameters explored in the sensitivity analysis are:

- Losses of storage
- Labour demand
- Fungicide usage
- Apple price

* Cost of production
* Environmental Impact Quotient (EIQ)
* EIQ by its components

6.2 Losses in storage analysis

One of the characteristics of the new apple variety is its performance in the cold store conditions. Thus, it would be interesting to explore how changes in the rate of losses affect the GP model results. Table 6.1 presents both the results and the technical coefficients taken into account for each run. In this case, weights attached to the goals were fixed to 1, (w1=w2..w5=1). The rest of the parameters were fixed at the average value for the existing apple varieties.

Table 6.1 Sensitivity analysis results for cold store performance

Runs	R1	R2	R3	R4
Weights	w1=w2=..w5=1	w1=w2=..w5=1	w1=w2=..w5=1	w1=w2=..w5=1
Cost Prod NV ECUs	4392.08	4392.08	4392.08	4392.08
Yield/ha NV Tonnes	36.7	36.7	36.7	36.7
Price NV ECU/tonne	430	430	430	430
EIQ P NV	1117.41	1117.41	1117.41	1117.41
EIQ C NV	318.89	318.89	318.89	318.89
EIQ E NV	3158.74	3158.74	3158.74	3158.74
EIQ Total	4595.04	4595.04	4595.04	4595.04
Total Produc. Tonnes	2300000	2300000	2300000	2300000
% losses (storage)	0.33	0.43	0.53	0.63
Total land ha	80105.23	80105.23	80105.23	80105.23
GD(ha)	11458.37	11458.37	11458.37	11458.37
RD(ha)	28650.53	29000.65	29339.99	29673.17
IM(ha)	2195.36	2195.36	2195.36	2195.36
OT(ha)	11717.01	11353.43	11001.06	10655.07
NV(ha)	26083.93	26097.39	26110.43	26123.24
Imports tonnes	0	3833.77	9665.93	15392.27
Exports tonnes	40000	40000	40000	40000
Exports ECU/tonnes	450	450	450	450
Income %	47.61	46.19	44.67	43.18
Income ECUs	119030938	115473844	111676360	107950895
EIQ P %	45.28	45.31	45.33	45.36
EIQ C %	34.41	34.43	34.45	34.46
EIQ E %	60.96	61.00	61.03	61.06
EIQ Total EIQ	53.56	53.58	53.61	53.63
Labour %	102	102	102	102

The model is quite sensitive to the losses in storage. A small increase of losses of only 0.10% will lead to a marked difference in apple imports and income. The import of apples into Italy increases from 0 tonne to 3833 tonnes per year. Because of this, total income at the Italian level, falls from approximately 119 million ECUs to almost 115 million ECUs. It should be noted here that the economic impact could be different between countries due to differences in both the cost of storage and type of storage.

Increasing the rate of losses in storage by 0.10% causes a decrease of 3% on the total Italian income. The maximum rate of losses per month tested in the analysis was 0.63% of losses per month. As expected, the effects in this case, are even more important. Imports ranged from 0 tonne to 15392 tonnes per year. Income results move away from the economic target by approximately 3.5%. In absolute terms, a fall of 11 million of ECUs is observed for the Italian apple industry. However, the new variety is disease resistant, it is logical to think that losses in storage will be reduced.

There are no significant changes in either the EIQ goal nor for the labour goal.

6.3 Labour demand analysis

Labour demand is another parameter which is expected to be sensitive to changes. An evaluation of the impact of varying the use of labour was tested by first increasing and then decreasing the numerical values of labour use. Table 6.2 presents the corresponding results to model runs 5 to 10.

The labour coefficients used for these runs were obtained from the existing apple varieties in Italy. Average labour use is 585 hours per hectare (including harvest, pruning and others), whereas the highest use of labour registered in Italy is almost 15 % more than the average, with the lowest requirement in labour being 18 % under the average value. Therefore, such percentages of labour use variation were included for the sensitivity analysis.

Table 6.2 Sensitivity analysis results varying labour demand

Runs	R5	R6	R7	R8	R9	R10
Weights	w1=w2=...w5=1	w1..w4=1,w5=10	w1=w2=...w5=1	w1..w4=1,w5=10	W1=w2=...w5=1	w1..w4=1,w5=10
Cost Prod NV ECUs	4392.08	4392.08	4392.08	4392.08	4392.08	4392.08
Yield/ha NV Tonnes	36.7	36.7	36.7	36.7	36.7	36.7
Price NV ECU/tonne	430	430	430	430	430	430
EIQ P NV	1064.02	1064.02	1064.02	1064.02	1064.02	1064.02
EIQ C NV	369.6	369.6	369.6	369.6	369.6	369.6
EIQ E NV	3286	3286	3286	3286	3286	3286
EIQ Total	4719.62	4719.62	4719.62	4719.62	4719.62	4719.62
Labour use Hours/ha	478	478	671	671	585	585
Total Produc. Tonnes	2300000	2300000	2300000	2300000	2300000	2300000
% losses (storage)	0.33	0.33	0.33	0.33	0.33	0.33
Total land ha	80105.23	80105.23	80105.23	80105.23	80105.23	80105.23
GD(ha)	11458.37	11458.37	11458.37	11458.37	11458.37	11458.37
RD(ha)	14628.15	4956.9	19020.59	12448.58	19046.79	18428.12
IM(ha)	2195.36	2195.36	2195.36	2195.36	2195.36	2195.36
OT(ha)	23127.77	33170.76	18566.5	25391.13	18539.29	19181.75
NV(ha)	28695.55	28323.81	28864.38	28611.77	28865.39	28841.61
Imports tonnes	0	0	0	0	0	0
Exports tonnes	29313.68	29313.68	29313.68	29313.68	29313.68	29313.68
Exports ECU/tonnes	300	300	300	300	300	300
Income %	71.48	71.96	53.13	19.93	59.71	43.00
EIQ P %	67.26	66.38	67.66	73.28	67.66	67.60
EIQ C %	51.10	50.44	51.41	55.68	51.41	51.36
EIQ E %	90.56	89.38	91.08	98.66	91.08	91.02
EIQ Total EIQ	79.53	78.50	80.00	86.66	80.01	79.95
Labour %	98.78	99.77	110.32	101.49	104.98	100.00

With regards to the weights attached to the deviation variables, two different scenarios were simulated in addition to these labour use coefficients: i) the same weight of 1 for the all goals (w1,w2..w5=1) and, ii) the weight of 10 for the labour goal, (w1..w4=1,w5=10). Runs 6, 8 and 10 (in Table 6.2) were carried out attaching an extra weight of 10 to the labour goal.

The model is clearly sensitive to labour requirements. An increase of 15% in total labour per hectare causes a decrease of 45% in the total value of income. In the opposite situation, where total labour use per hectare decreases by 18%, the GP output increases income by 67%. Table 6.2 shows the level of achievement of the income goal. For instance, the economic goal is only 71% achieved when the level of labour used is the smallest (478 hours/ha/year), but where 671 hours of labour is needed for growing a hectare of apples, only 20% of this goal is achieved. However, income becomes less sensitive when the same importance is given to all goals (w1,w2..w5=1)

The labour goal is fully achieved when the technical coefficient used is the average (585 hours/ha/year) and when an extra weight of 10 is attached to labour goal. Nevertheless, when the technical coefficient used is the highest (671 hours/ha/year) and the same importance is given to each goal, the labour goal presents a deviation of +10 %. This is the maximum deviation registered of the desired labour target, but since the goal is to maintain the status quo, it represents non-achievement.

6.4 Fungicide usage analysis

The fungicide usage level is another parameter that would be interesting to explore. Basically, a new disease resistant apple variety will have a lower fungicide usage than the existing varieties. For this reason, it was included in this sensitivity analysis. R11 shows the GP model output when the new variety was assumed to have the same technical coefficients as the existing varieties. R12-14 show a 10% less use of fungicide in each case. Table 6.3 shows the solutions generated by attaching a weight of 1 to all goals and different values of fungicide usage on the new variety. Therefore, the same importance was given to all goals. EIQ coefficients were fixed at a medium value.

Unexpectedly, large changes in fungicide usage are not reflected on the income goal. For instance, by decreasing the use of fungicide by 30%, the Italian income is increased by only 3% (see Table 6.3). These results can be explained because of the cost of production structure. Table 3.4 (page 79) shows the apple production costs structure for Emilia Romagna (Italy). For this Italian region, fungicides represent approximately 3.6

% of the total cost of apple production. Therefore, an important decrease on the fungicide usage will not cause a considerable increase of the Italian income, and vice versa.

Table 6.3 Sensitivity analysis results for fungicide usage

Runs	R11	R12	R13	R14
Weights	W1=w2=...w5=1	w1=w2=...w5=1	w1=w2=...w5=1	w1=w2=...w5=1
Cost Prod NV ECUs	4392.08	4392.08	4392.08	4392.08
Yield/ha NV Tonnes	36.7	36.7	36.7	36.7
Price NV ECU/tonne	430	430	430	430
EIQ P NV	1850.48	1850.48	1850.48	1850.48
EIQ C NV	642.78	642.78	642.78	642.78
EIQ E NV	5714.96	5714.96	5714.96	5714.96
EIQ Total	8208.22	8208.22	8208.22	8208.22
Fungicide kg/ha	44.99	40.49	38.24	35.99
Labour use Hours/ha	585	585	585	585
Total Produc. Tonnes	2300000	2300000	2300000	2300000
% losses (storage)	0.33	0.33	0.33	0.33
Total land ha	80105.23	80105.23	80105.23	80105.23
GD(ha)	11458.37	11458.37	11458.37	11458.37
RD(ha)	17043.105	17043.105	17043.10481	17043.10481
IM(ha)	2195.36	2195.36	2195.36	2195.36
OT(ha)	20620	20620	20620	20620
NV(ha)	28788.37	28788.37	28788.37	28788.37
Imports tonnes	0	0	0	0
Exports tonnes	29313.68	29313.68	29313.68	29313.68
Exports ECU/tonnes	300	300	300	300
Income %	40.34	40.83	41.08	41.33
Income Total ECUs	100857260	102086394	102700961	103315528.6
EIQ P %	24.99	24.99	24.99	24.99
EIQ C %	18.99	18.99	18.99	18.99
EIQ E %	33.64	33.64	33.64	33.64
EIQ Total EIQ	29.56	29.56	29.56	29.56
Labour %	100.00	100.00	100.00	100.00

In this analysis, however, it was assumed that, in spite of changes in the fungicide usage, no changes would occur in the EIQ values. This is not totally true, since if the amount of fungicide is reduced the EIQ value should be smaller. Later, both situations are taken into account in a slightly more complex sensitivity analysis (sub-section 6.7).

6.5 Apple price analysis

The model has also been tested for changes on the new apple variety prices. The basic price selected was taken as the highest observed for the existing apple varieties. R18 has been run with an increased price of 10% while R17 and R16 have been run with an increased price of 15 and 20% respectively. R15 has been run with an average price of the existing apple varieties. The rest of the parameters have been fixed at the average values of the existing apple varieties. Table 6.4 shows the GP model outputs.

An extra price of 15% enables the Italian apple industry to increase its income by approximately 22%. The income increases by almost 11% where the simulated price is 10% greater than the basis selected price and this value reaches 46% when the run simulates an increased price of 20%. No significant changes were observed for either the EIQ goal, or the labour goal.

Finally, R19 was run with an extra weight of 10 attached to the income goal, assuming an increase of 5% on the existing price. Under these conditions, the GP model solution improves the Italian income by almost 30 million ECU. However, when the run (R18) gives the same importance to all goals the Italian income is improved by only 17 million ECU. With regards to use of land, R19 reduces by almost 50% the number of hectares under Red Delicious, increasing the number of hectares of "other apple varieties". This change could be explained due to "other varieties" having a more profitable return than the rest of the apple varieties. The share occupied by the new variety ranges between 34.7 and 36% of the total Italian land under apples.

Table 6.4 Sensitivity analysis results for new apple variety price

Runs	R15	R16	R17	R18	R19
Weights	W1,w2..w5=1	w1,w2..w5=1	w1,w2..w5=1	w1,w2..w5=1	w1=10 w2=...w5=1
Cost Prod NV ECUs	4392.08	4392.08	4392.08	4392.08	4392.08
Yield/ha NV Tonnes	36.7	36.7	36.7	36.7	36.7
Price NV ECU/tonne	450	540	495	472.5	472.5
Price NV		(450 x 1.2)	(450 x1.15)	(450 x1.10)	(450 x1.10)
EIQ P NV	1064.02	1064.02	1064.02	1064.02	1064.02
EIQ C NV	369.6	369.6	369.6	369.6	369.6
EIQ E NV	3286	3286	3286	3286	3286
EIQ Total	4719.62	4719.62	4719.62	4719.62	4719.62
Labour use Hours/ha	585	585	585	585	585
Total Produc. Tonnes	2300000	2300000	2300000	2300000	2300000
% losses (storage)	0.33	0.33	0.33	0.33	0.33
Total land ha	80105.23	80105.23	80105.23	80105.23	80105.23
GD(ha)	11458.37	11458.37	11458.37	11458.37	13698.76
RD(ha)	19020.59	20986.31	20986.31	20986.31	10257.57
IM(ha)	2195.36	2195.36	2195.36	2195.36	2195.36
OT(ha)	18566.5	16525.23	16525.23	16525.23	26151.58
NV(ha)	28864.38	28939.94	28939.94	28939.94	27801.93
Imports tonnes	0	0	0	0	0
Exports tonnes	29313.68	29313.68	29313.68	29313.68	29313.68
Exports ECU/tonnes	300	300	300	300	300
Income %	67.55	98.85	82.60	74.47	79.45
Income ECUs	168870830.2	247119240.6	20649472.9	186181489.0	198633529.7
EIQ P %	67.66	67.83	67.83	67.83	65.16
EIQ C %	51.41	51.54	51.54	51.54	49.51
EIQ E %	91.08	91.33	91.33	91.33	87.73
EIQ Total EIQ	80.00	80.22	80.22	80.22	77.06
Labour %	104.98	104.8	104.8	104.8	105.74

6.6 Yields of the new variety analysis

The achievement of the economic goal is sensitive to changes in the yield per hectare of the new variety. Runs 20 to 22 were run giving the same importance to each goal. An extra weight of 10 was attached to goals 2,3 and 4 (environmental goals) for the runs 23 to 25. Comparing run 21 and 20, despite the yield per hectare of the new variety being the smallest, the GP model solution increases considerably the number of hectares cultivated with both the new variety and others by approximately 14 and 54 %

respectively. In addition, exports are increased by 37.5 %. Besides this, an achievement of 91% of the EIQ goal is observed, with the labour target almost achieved. At the same time, however, income is decreased by 55%. In order to satisfy the EIQ target, the GP model increases the number of hectares under the new apple variety. However, the model also increases greatly the number of hectares cultivated with "other" varieties. This can be explained by both the high profitability of "other" varieties and its high yield per hectare. The amount of hectares cultivated under the rest of the apple varieties were chosen by the model, respecting the minimum allowed by the model constraints.

By comparing R21 and R22, there are no changes in exports and there is an increase of 9% in the income. Nevertheless, there is an decrease of almost 18% in the achievement of the EIQ goal.

Where an extra weight of 10 is attached to the environmental goal, the GP model results are substantially different. For instance, R23 shows a drastic fall in the income, resulting in a negative return meaning the labour goal is unachieved by 31%. However, the environmental target is improved by approximately 20%. As weight 10 was attached to EIQ target, the GP model is forced to chose more hectares of the new variety, since this variety has the smallest value for EIQ. Nevertheless, the yield per hectare is the smallest as well, resulting, therefore, in an increase of 17% of the land use under apple cultivation. The model must increase the total number of hectares in order to satisfy the apple demand. Nevertheless, when this parameter is changed to the highest yield per hectare (R25), the following effects are observed. Exports are increased by approximately 600%, the number of hectares cultivated with Red Delicious are duplicated and there is a small fall in income. The increase of exports can explain the reduction of the income, because the apple price for export was fixed at a very low price of 300 ECUs per tonne. Another reason could be the new variety price, since the runs were carried out assuming an average price for the new apple variety.

Table 6.5 Sensitivity analysis for new apple variety yields

Runs	R20	R21	R22	R23	R24	R25
Weights	W1=w2=..w5= 1	w1=w2=..w5=1	w1=w2=..w5=1	w1=w5=1,w2..w4=10	w1=w5=1,w2..w4=10	w1=w5=1,w2..w4=10
Cost Prod NV ECUs	4392.08	4392.08	4392.08	4392.08	4392.08	4392.08
Yield/ha NV Tonnes	20.22	36.7	41.08	20.22	36.7	41.08
Price NV ECU/tonne	430	430	430	430	430	430
EIQ P NV	1064.02	1064.02	1064.02	1064.02	1064.02	1064.02
EIQ C NV	369.6	369.6	369.6	369.6	369.6	369.6
EIQ E NV	3286	3286	3286	3286	3286	3286
EIQ Total	4719.62	4719.62	4719.62	4719.62	4719.62	4719.62
Labour use Hours/ha	585	585	585	585	585	585
Total Produc. Tonnes	2300000	2300000	2300000	2300000	2300000	2300000
% losses (storage)	0.33	0.33	0.33	0.33	0.33	0.33
Total land ha	80105.23	80105.23	80105.23	104027.3	80105.23	80105.23
GD(ha)	11458.37	11458.37	11458.37	11458.37	11458.37	11458.37
RD(ha)	4956.9	19020.59	19112.8	4956.9	31679.6	28975.76
IM(ha)	2195.36	2195.36	2195.36	2195.36	2195.36	2195.36
OT(ha)	28609.02	18556.5	24714.78	5420.92	5420.92	6217.94
NV(ha)	32885.55	28864.38	22623.9	79995.71	29350.96	31257.8
Imports tonnes	0	0	0	0	0	0
Exports tonnes	40302.07	29313.68	29313.68	29313.68	93949	190851.79
Exports ECU/tonnes	300	300	300	300	300	300
Income %	33.02	60.03	65.49	-51.09	48.87	47.40
Income ECUs	82570215	150089946	163729832	-127746721	122186825	119204594
EIQ P %	77.09	67.66	53.03	83.67	68.80	54.30
EIQ C %	58.57	51.41	40.29	63.57	52.27	41.26
EIQ E %	91.32	91.10	71.40	112.65	92.62	73.10
EIQ Total EIQ	91.16	80.01	62.71	98.95	81.36	64.21
Labour %	101.20	104.98	106.12	131.27	103.80	104.48

6.7 Cost of production analysis

In this particular analysis, three different numerical values of costs of production were taken into account in order to explore changes at the Italian apple industry. As described in Chapter 3, the GP model has two components for representing the total cost of apple production, i.e. the costs due to the use of pesticides, fungicides and labour and, the remaining costs. A sensitivity analysis was thus carried out changing the costs associated with these remaining costs. The model was tested with three different levels, low (3500ECU/ha), medium (4392.08ECU/ha) and high (4615.1ECU/ha). These values were extracted from the information obtained from Confcooperative, (1993). Results are presented in Table 6.6.

A decrease of 20% in these costs of production causes an increase of only 16% in the total income. Conversely, increasing the cost of production by 5%, the resulting decrease is approximately 3%. Therefore, this component of the cost of production does not seem to be a particularly sensitive parameter. This result can be explained by the fact that this component represents only the 30% of the total cost of production. Consequently, for instance, an increase of 10% in this parameter has an effect on the total cost of production of only 3%.

Table 6.6 Sensitivity analysis for new variety cost of production

Run	R26	R27	R28	R29	R30	R31
Weights	w1=w2=..w5=1	w1=w2=..w5=1	W1=w2=..w5=1	W1=10,w2=..w5=1	w1=10,w2=..w5=1	w1=10,w2=..w5=1
Cost Prod NV ECUs	3500	4392.08	4615.1	3500	4392.08	4615.1
Yield/ha NV Tonnes	36.7	36.7	36.7	36.7	36.7	36.7
Price NV ECU/tonne	430	430	430	430	430	430
EIQ P NV	1064.02	1064.02	1064.02	1064.02	1064.02	1064.02
EIQ C NV	369.6	369.6	369.6	369.6	369.6	369.6
EIQ E NV	3286	3286	3286	3286	3286	3286
EIQ Total	4719.62	4719.62	4719.62	4719.62	4719.62	4719.62
Total Produc. Tonnes	2300000	2300000	2300000	2300000	2300000	2300000
% losses (storage)	0.33	0.33	0.33	0.33	0.33	0.33
Total land ha	80105.23	80105.23	80105.23	80105.23	80105.23	80105.23
GD(ha)	11458.37	11458.37	11458.37	19093.11	19164.72	19164.72
RD(ha)	20986.31	19046.8	19020.59	8128.97	8082.35	8082.35
IM(ha)	2195.36	2195.36	2195.36	2195.36	2195.36	2195.36
OT(ha)	16525.23	18539.3	18566.5	24714.78	24714.78	24714.78
NV(ha)	28939.94	28865.39	28864.38	25972.98	25948.00	25948.00
Imports tonnes	0	0	0	0	0	0
Exports tonnes	29313.68	29313.68	29313.68	29313.68	29313.68	29313.68
Exports ECU/tonnes	300	300	300	300	300	300
Income %	69.45	59.71	57.77	75.47	67.36	65.05
Income ECUs	173630019	149270774	144425005	188676214	168409258	162622333
EIQ P %	67.83	67.66	67.66	60.88	60.82	60.82
EIQ C %	51.54	51.41	51.41	46.25	46.21	46.21
EIQ E %	91.33	91.08	91.08	81.95	81.89	81.89
EIQ Total EIQ	80.22	80.01	80.01	71.99	71.92	71.92
Labour %	104.80	104.98	104.98	105.8	105.80	105.80

6.8 Environmental Impact Quotient (EIQ) analysis

Changes at the EIQ levels were tested in order to explore potential sensitivities to this parameter. In order to improve the analysis of this parameter, it would had been necessary to have more information about the performance of the new apple variety available. This means to know exactly which active ingredients and its corresponding amount per hectare are going to be used for controlling the pest and diseases (the EIQ impact varies between active ingredient). Due to this lack of information, a sensitivity analysis was carried out assuming a set of different possible scenarios. Table 6.7 presents the results after running the GP model. Five different levels of EIQ were simulated and two different scenarios; i) giving the same importance to all goals (w1w2..w5=1) and, ii) penalising with an extra-weight of 10, the unachieved environmental goal (w1w5=1,w2..w4=10).

This was tested by decreasing the three EIQ component values by 10% from the values observed in the existing apple varieties. In addition, a reduction of the fungicide usage was made. Consequently, R32-41 have been run varying both the EIQ values and the amount of fungicides per hectare applied to the apple orchard.

If the new apple variety had an EIQ value 10% smaller than the existing varieties (R32), the total EIQ value for the Italian apple industry would be reduced by about 30 million EIQ units and, the environmental goal would be achieved by only 14%. It is important to highlight that the number of hectares cultivated with the new variety is 34.7% of the total land. One of the constraints is that at least 30% of the total land must remain occupied by the existing varieties. Therefore, the model is allowed to incorporate hectares with new apple variety only on the remaining 70% of the total land, i.e. approximately 56.000 hectares. R33 was carried out including an extra decrease of 10% in the EIQ coefficients. Under this assumption, the EIQ goal becomes more sensitive, increasing the achievement of the EIQ goal to approximately 28%. However, this parameter does not seem to have impact on both the economic and labour goals. When the weights attached are 1 for all goals, the achievement of income ranges from 66.9 to 69.9%. Similar variation is observed on the labour goal, ranging from 98.3 to 102.3%.

When an extra weight of 10 is attached to the EIQ goals (goals 2 to 4) and the EIQ values are reduced by 40%, the target is achieved by more than 80% (R41). At the same time, the number of hectares cultivated with the new apple variety reaches its maximum value of 29,200 hectares. Again, under this scenario, there appears to be only a small effect on both the income and labour goals. Exports and imports also remain unchanged, since yields have not been modified.

Table 6.7 Sensitivity analysis results for Environmental Impact Quotient

Runs	R32	R33	R34	R35	R36	R37	R38	R39	R40	R41
Weights	w1=w2=..w5=1	w1=w2=..w5=1	w1=w2=..w5=1	w1=w2=..w5=1	w1=w2=..w5=1	w1=w5=1w2..w4=10	w1=w5=1w2..w4=10	w1=w5=1w2..w4=10	w1=w5=1w2..w4=10	w1=w5=1w2..w4=10
Cost Prod NV ECUs	4392.08	4392.08	4392.08	4392.08	4392.08	4392.08	4392.08	4392.08	4392.08	4392.08
Yield/ha NV Tonnes	36.7	36.7	36.7	36.7	36.7	36.7	36.7	36.7	36.7	36.7
Price NV ECU/tonne	430	430	430	430	430	430	430	430	430	430
EIQ P NV	2081.79	1850.48	1619.17	1387.86	1064.02	2081.79	1850.48	1619.17	1387.86	1064.02
EIQ C NV	723.13	642.78	562.43	482.08	369.6	723.13	642.78	562.43	482.08	369.6
EIQ E NV	6429.33	5714.96	5000.59	4286.22	3286	6429.33	5714.96	5000.59	4286.22	3286
EIQ Total	9234.25	8208.22	7182.19	6156.16	4719.62	9234.25	8208.22	7182.19	6156.16	4719.62
Total Produc. Tonnes	2300000	2300000	2300000	2300000	2300000	2300000	2300000	2300000	2300000	2300000
% losses (storage)	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33
Total land ha	80105.23	80105.23	80105.23	80105.23	80105.23	80105.23	80105.23	80105.23	80105.23	80105.23
GD(ha)	13677.15	11458.37	11458.37	11458.37	11458.37	11458.37	11458.37	11458.37	11458.37	11458.37
RD(ha)	10257.76	12448.58	14628.15	16817.26	17043.1	18465.47	27945.54	27945.54	27945.54	27945.54
IM(ha)	2195.36	2195.36	2195.36	2195.36	2195.36	2195.36	2195.36	2195.36	2195.36	2195.36
OT(ha)	26165.99	25391.13	23127.77	20854.53	20620	19142.96	9298.5	9298.5	9298.5	9298.5
NV(ha)	27808.94	28611.77	28695.55	28779.69	28788.37	28843.04	29207.43	29207.43	29207.43	29207.43
Imports tonnes	0	0	0	0	0	0	0	0	0	0
Exports tonnes	29313.68	29313.68	29313.68	29313.68	29313.68	29313.68	29313.68	29313.68	29313.68	29313.68
Exports ECU/tonnes	300	300	300	300	300	300	300	300	300	300
Income %	69.98	68.44	67.66	66.64	66.96	63.78	53.85	54.35	54.85	55.60
EIQ P %	12.06	24.83	37.360	49.96	67.48	12.51	25.35	38.02	50.70	68.45
EIQ C %	9.16	18.87	28.39	37.96	51.27	9.51	19.26	28.90	38.52	52.01
EIQ E %	16.25	33.44	50.29	67.26	90.83	16.85	34.13	51.19	68.27	92.16
EIQ Total EIQ	14.27	28.38	44.19	59.09	79.80	14.80	29.98	44.98	59.96	80.95
Labour %	98.38	98.49	99.04	99.59	99.64	100.00	102.38	102.38	102.38	102.38

6.8.1 The effects of varying the EIQ components

As described in Chapter 3 (3.4) the EIQ is made of three different components, i.e. field-workers (EIQ P), consumers (EIQ C) and ecological (EIQ E). In this case, a further sensitivity analysis was developed, by means of varying only the value of one of these components, leaving the others fixed at the existing apple varieties values. Twelve runs of the GP model were carried out using the following set of attached weights; R42 to 50 w1,w2..w5=1, and R51 to 53 were run attaching the value of 10 to each EIQ component. In turn, three situations were simulated for such components; i) a decrease value of 10%, ii) a decrease value of 20% and, iii) a decrease value of 30% for each EIQ component. The corresponding results are presented in Table 6.8.

As expected, the GP model is more sensitive to changes in the EIQ E (ecological component) since with a decrease of 30% of this component, the EIQ value reaches almost 30% of the environmental target. Unlike the EIQ E, the same level of change (30%) on the EIQ C (consumers), results in an achievement of only 3.45% of the environmental target. The sensitivity to EIQ E changes can be explained because this component has the highest absolute value among the three components and therefore, the most relative importance. Thus, changes in EIQ E will have an important effect on the total EIQ units.

When the model is run with an additional weight of 10 on the EIQ P, (for instance R42 and 51) the achievement of the environmental goal (total EIQ goal) is improved by approximately 14%. However, when the same weight is attached to EIQ E, the EIQ goal is improved by 25%. Therefore, again, the EIQ E is the most sensitive of the EIQ components.

With regard to changes in the use of land, there are some points to be stressed. First, there are no significant changes when EIQ P is the parameter taken into account (R42-44). Second, the number of hectares cultivated with Red Delicious is increased by

100%, to the detriment of Golden Delicious, where EIQ E is the changed parameter (R48-50). The same situation is observed when the parameter explored is EIQ C (R45-47. Third, Imperatore di Roma seems to be an apple variety that does not show changes, from the use of land point of view, since in all runs the GP model selected the minimum allowed.

Table 6.8 Sensitivity analysis varying the EIQ components

	R42	R43	R44	R45	R46	R47	R48	R49	R50	R51	R52	R53
	w1=w2=..w5=1	w1=w2=..w5=1	w1=w2=..w5=1	w1=w2=..w5=1	w1=w2=..w5=1	w1=w2=..w5=1	w1=w2=..w5=1	w1=w2=..w5=1	w1=w2=..w5=1	w2=10,w1w3..w5=1	w3=10,w1w2w4..w5=1	w4=10,w1w2w3w5=1
Cost Prod NV ECUs	4392.08	4392.08	4392.08	4392.08	4392.08	4392.08	4392.08	4392.08	4392.08	4392.08	4392.08	4392.08
Yield/ha NV Tonnes	36.7	36.7	36.7	36.7	36.7	36.7	36.7	36.7	36.7	36.7	36.7	36.7
Price NV ECU/tonne	430	430	430	430	430	430	430	430	430	430	430	430
EIQ P NV	2081.79	1850.48	1619.17	2313.1	2313.1	2313.1	2313.1	2313.1	2313.1	2081.79	2313.1	2313.1
EIQ C NV	803.48	803.48	803.48	723.13	642.78	562.43	803.48	803.48	803.48	803.48	723.13	803.48
EIQ E NV	7143.7	7143.7	7143.7	7143.7	7143.7	7143.7	6429.33	5714.96	5000.29	7143.7	7143.7	6429.33
EIQ Total	10028.97	9797.66	9566.35	10179.93	10099.58	10019.23	9545.91	8831.54	8116.87	10028.97	10179.93	9545.91
Total Produc. Tonnes	2300000	2300000	2300000	2300000	2300000	2300000	2300000	2300000	2300000	2300000	2300000	2300000
% losses (storage)	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33
Total land ha	80105.23	80105.23	80105.23	80105.23	80105.23	80105.23	80105.23	80105.23	80105.23	80105.23	80105.23	80105.23
GD(ha)	21874.19	19164.72	20267.42	20267.42	11458.37	11458.37	29654.82	20267.42	15838.91	11458.37	11458.37	13698.76
RD(ha)	10261.44	8082.35	10261.44	10251.5	13099.89	13099.89	5195.53	10251.5	10247.75	13099.89	13099.89	12427.31
IM(ha)	2195.36	2195.36	2195.36	2195.36	2195.36	2195.36	2195.36	2195.36	2195.36	2195.36	2195.36	2195.36
OT(ha)	20620	24714.78	21706.08	21716.7	24714.78	24714.78	20620	21716.7	24714.78	24714.78	24714.78	23898.44
NV(ha)	25154.21	25948	25674.62	25674.23	28636.81	28636.81	22439.49	25674.23	27108.4	28636.8	28636.8	27885.33
Imports tonnes	0	0	0	0	0	0	0	0	0	0	0	0
Exports tonnes	29313.68	29313.68	29313.68	29313.68	29313.68	29313.68	29313.68	29313.68	29313.68	29313.68	29313.68	29313.68
Exports ECU/tonnes	300	300	300	300	300	300	300	300	300	300	300	300
Income %	67.85	67.36	67.21	67.46	62.81	62.81	69.09	67.46	65.79	60.36	60.36	61.96
EIQ P %	10.91	22.53	33.43	0.00	0.00	0.00	0.00	0.00	0.00	12.43	0	0
EIQ C %	0.00	0.00	0.00	8.47	18.89	28.33	0.00	0.00	0.00	0	9.44	0
EIQ E %	0.00	0.00	0.00	0.00	0.00	0.00	13.11	30.01	47.51	0	0	16.3
EIQ Total EIQ	2.91	6.00	8.92	1.04	2.30	3.45	8.01	18.34	29.06	3.31	1.15	9.97
Labour %	105.52	105.80	105.57	105.57	105.53	105.53	105.79	105.57	105.68	105.5321201	105.5321211	105.536241

6.9 Conclusion

This phase of the study has provided a major learning experience for model formulation and allows us to consider confidence in the model. In this case, the model had to be modified, since a few problems were detected in the model structure. Therefore, sensitivity analysis helps us to improve particular aspects of the model design.

Conversely, the results of this sensitivity analysis have indicated that it was possible to identify the sensitive parameters defined throughout the thesis. The sensitivity analysis also provides information to the research project for giving priorities to those characteristics of the new variety to be improved. For instance, the performance of the apple in cold store, having a large effect due the income goal.

The yield per hectare is another parameter identified as a sensitive, with the impact of this parameter being mainly on the income goal. However, unlike yield, the requirement of labour has a large impact on both economic and social aspects.

Finally, the EIQ E component was the most sensitive parameter within the EIQ component. Here, a significant shortage of available data of the new apple variety hampered a deeper analysis of this parameter. Although the entire sensitivity analysis of EIQ was carried out with "guessestimated" data, it was possible to improve the understanding of this parameter and, in addition how the introduction of a new apple variety would affect the total amount of EIQ units in a particular region or country.

In the next Chapter, conclusions and limitations of the present study are presented. The discussion mainly focuses on the applicability of the GP model for the EU apple industry as a tool useful for evaluating the introduction of new apple varieties. Further, suggestions for future research work are provided.

Chapter 7
Conclusions and Future Research

7.1 Introduction

The European Union apple market demands a high quality blemish-free product, thus dictating an intensive pattern of pesticide use to control pests and diseases. The apple orchard requires continuous use of chemical spray against insect and fungal diseases during its operational life. Further, this pattern of intensive agro-chemical management has created social, economic and environmental impacts with hundreds of millions of people being exposed to pesticides each year.

The general objectives of this study were to:

- To develop a flexible mathematical programming model, that includes economic, social and environmental parameters and which could be used to explore the impacts of the introduction of new apple varieties into the European Union on those variables.
- To assess the socio-economic and environmental impact of the DEAC project at European Community level as a result of the introduction of new apple varieties.
- To assess the suitability of the MCDM approach for assisting decision making by both researchers and policy makers at regional, national or EU level.

A Goal Programming (WGP) model was selected as the methodology, and it was concluded that substantial benefits can be expected from the introduction of a new disease resistant apple variety into the EU apple industry. The WGP model developed was demonstrated to be a useful tool capable of addressing conflicting objectives.

This Chapter will evaluate the use of goal programming modelling for the assessment of the introduction of a new apple variety into the EU apple industry.

Section 7.3 discusses the possible use of the model. Section 7.4 discusses the main problems and limitations found for developing the model. Finally, section 7.5 identifies some issues for future that would improve the model developed in this thesis.

7.2 Evaluation of the methodology

What this study has shown, is that the use of mathematical model in particular GP model proved capable of identifying the magnitude and direction of changes that are probably to take place from the introduction of a new apple variety. It was possible to develop a flexible mathematical model that includes economic, social and environmental parameters. It is also possible to combine both monetary and non-monetary variables in a single decision-making framework. Therefore, the primary hypothesis (page 17) of the study has been confirmed.

MCDM seemed to be an adequate approach in order to deal with the complex problem of pesticide use in agriculture sector in particular, in the EU apple industry. The Weighted Goal Programming model used in this study allowed different goals to be weighted according to the importance attached. In addition, it provided the advantage of being able to simultaneously, consider all goals in a composite objective function.

According to Romero (1991) one of the main criticisms against the GP approach lies in its inherent capacity to generate nonefficient or dominated solutions. Consequently, this author suggested a procedure in order to check if the solution provided by a GP model satisfies or not the Paretian condition of efficiency. Unfortunately, this procedure was not applied to this GP model, mainly due to lack of time. However, target levels have been specified at a high and low value (not reachable) for income and EIQ value respectively. This could ensure that a non-dominated solution will be generated by WGP model. With regard to labour goal, it was established as a two-side goal forcing the goal to be satisfied exactly.

7.3 Possible use of the GP model

As stated in Chapter 1 the main objective of the DEAC project was to breed new apple varieties which would meet the market demand for high quality products, whilst requiring a greatly reduced chemical input at the farm level. This study shows that it is possible to evaluate the potential social, economic and environmental impacts that occur when a new apple variety is developed and introduced into the EU apple industry. Despite the problems of developing the GP model, and particularly in data availability, the approach was found to be effective in determining the potential impacts of the DEAC project, and for that matter, any project considering the impacts of the introduction of a new technology.

The use of the GP framework provides for the (transferable) examination of complex systems where trade-offs are commonplace in the decision-making process. Orchard owners will undoubtedly have different goals from policy makers, who will in turn have different goals from consumers. The modelling process allows for a greater understanding of the complex linkages and inter-dependencies that exist in agricultural and environmental systems.

The GP model also proved to be useful for identifying those apple characteristics that would have a major negative impact on the apple industry. For example, the rate of losses in cold store has a very large impact on the economic results. Therefore, the model can provide to scientists who are involved in developing new apple varieties with important information before technology research programs are developed.

Another example is the use of labour that the new apple variety will demand. The model showed that this parameter has a great impact on both economic and social aspects. In this way, therefore, the model is not only shown to provide a useful policy framework, but also a tool which can (or should) be used as a pre-cursor to scientific investigation.

The parameter chosen for measuring the environmental impacts was the Environmental Impact Quotient of Kovach *et al.*, (1992). The EIQ model describes the environmental impacts of pesticide usage in a way that can prove useful to policy makers and geneticists. One of the main advantages is that the EIQ model reduces the environmental impact to a single figure for ease of comprehension, and ease of use and compatibility with other decision making models, such as the GP model developed in this thesis. An additional advantage was that the EIQ was split into its components which allowed the users of the GP model to vary each of the numerical value separately. Therefore, increasing the usefulness for both DMs and scientists in developing new apple varieties with a lower degree of pesticide usage. It also provides effective information in order to determine in which component (field-workers, consumer and ecological) the introduction of a new apple variety will have major impact. At the same time, the GP model may allow geneticists to explore in depth which kind of pesticide shows the highest impact in reducing the total amount of EIQ units. Therefore, the GP model developed in this thesis can be used as a tool for guiding geneticists in relevant issues for future research. For instance, it would be possible to gain an insight into which pest and apple diseases would have the most significant environmental impact or which would be most sensitive from the introduction of a new resistant apple variety.

The EIQ approach also allows a comparison to be made between different pesticide strategies, such as between conventional and IPM strategies, and between different regions where local conditions dictate differing pesticide-use characteristics.

The modelling approach also proved to be effective in determining how land use under different apple varieties should be utilised to meet specified goals and in determining the impacts and trade-offs that would occur if certain decisions were made. This was clearly shown when the relative importance (weights) attached to each attribute were varied.

7.4 Limitation of the GP model

7.4.1 Data issue

One of the difficulties encountered during this thesis was the lack of specific published data available with reference to the European apple industry. Whereas the available literature provides data and information, it does not break it down into the precise details that were needed in order to feed the model. For instance, most of the information available from the European Commission is published under the heading of "apples". It does however, not go on to break it down into apple varieties.

The model was further affected by the difficulties, which arose from the deficiencies in data with regard to European growing regions (NUTS-2). The institutions that currently publish data provide it in aggregated form of, yields per hectare, production area, cost of production and so on. However, the model required more specific details in order to be run, therefore it was necessary for the study to assume that there was an equal distribution of land among the regions. This is the case for Greece.

The greatest limitation to the correct use of the GP model is the availability of reliable data, from which a model can be built and validated. As stated in Chapter 4 several assumptions must be made in order to counteract the lack of data. The primary limitation was that the model's run should be carried out by mean of "guessestimate" data of the new apple variety.

Therefore, the results of this study should be viewed not as a means of forecasting or predicting but rather as an analytical tool for evaluating the potential economic, social and environmental impacts of introducing a new apple variety and at the same time for making trade-offs between DM's preferences. As shown in section 7.2, the model provided a successful transferable framework for policy and environmental analysis, despite those source data problems, and also showed that such a study should actually be done first to reveal true (rather than perceived) data gaps.

7.4.2 Model goals

Several factors indicate that the GP model that has been developed in this study, actually under or overestimates the economic impact of the introduction of new apple variety.

Firstly, no account was taken of the fact that general reduction in the pesticide usage will be reflected in a reduction of expenditures in the national health services in each Member State of the Community. As mentioned in Chapter 3, taking into consideration the reduction in the use of pesticides demonstrated by this study for the new variety, it would follow that there will be a positive economic impact on the EU (health care systems), which benefit from the reduction in treatment costs. Pimental *et al.*, (1992) valued in almost 7,000 million ECU per year the total social and environmental costs from pesticide use in the USA. Which approximately 650 million ECU corresponds to the public health impacts.

Secondly, as stated in Chapter 6, the rate of losses in cold store has a very large impact on the economic results. The numeric value used to run the model could overestimate the overall total economic impact. The model results could have reflected a more realistic outcome if it had been possible to obtain data relating to both the losses in cold store per month, and losses in cold store with reference to storage systems.

Thirdly, the model did not represent changes in apple prices due to different fruit quality. The apple price is an average of all apple sizes.

Finally, it was not possible due to the time available, and for practical reasons to include data relating to pesticide use before apples going into cold store. However, had it been possible to represent this within this study it would have demonstrated another positive economic effect due to reduction of pesticides used during the storage process.

As already discussed in Chapter 5, the only parameter taken into account in the GP model was hours of labour. Nevertheless, there are other social implications, which were not included in the model. For example, there is a positive social impact derived from the use of a new disease resistant apple variety. This is reflected throughout the health of the populations. It would be relevant to establish the relationships between potential reduction in the pesticide patterns use and the improvement in the health of the population. As the World Health Organisation (WHO) determined for 1990, approximately 20,000 unintentional deaths due to pesticide poisoning. According to Dinham (1993) chronic toxicity is difficult to determine adequately, requiring long-term studies. Therefore, the GP model is not measuring this potential social impact.

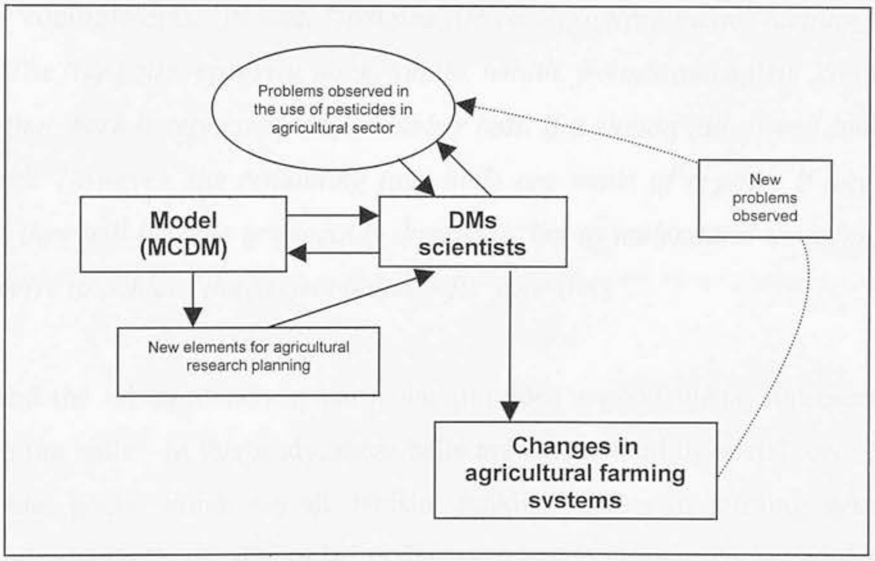
Another social impact that was not included in the model, was the result of the reduction in the use of pesticides, which would in turn substantially affect the agro-chemical industries in employment terms.

7.5 Future research

i. An additional improvement of the model would be to expand the approach including risk and uncertainty. The potential impact resulting of the introduction of a new apple variety within the EU in an uncertain environment could be explored using MOTAD and in turn within a MCDM framework (Romero and Rehman, 1989). Yield of apples, apple prices, and incidence of pest and diseases (existing and new varieties) would all lead to apply this approach.

ii. It is important also to involve different experts working as a multi-disciplinary team from the very beginning of a new research project planning. In this way the model can be used as a powerful tool for giving new elements to the establishment of research priorities and also being a linkage between problems observed in the use of pesticide and future research planning as is shown in Figure 7.1. The application of interactive methods within MCDM could be suitable in order to increase the interaction between DMs and the mathematical model (Romero and Rehman, 1989).

Figure 7.1 The use of MCDM model in an agricultural planning research process.



iii. This thesis combined the power of MCDM (GP) with the EIQ index for evaluating the introduction of a new apple variety. Nevertheless, the GP model developed would be greatly improved if the concept of sustainability is introduced and the scope of evaluating changes in the farming systems would be increased. The term of sustainability includes economic, social and environmental aspects (Bruin and Roex, 1994). The issue is to select the appropriate units for measuring impacts at farm and regional levels, so that they might be used in MCDM modelling approach.

7.6 Final comments

As stated, the model developed in this thesis could be improved, however, it is an initial approximation towards providing a GP model capable of helping DMs in a complex situation and, it also highlights the importance of issues such as environmental problems within the agricultural sector.

And finally: during a graduation speech for students emerging from a University, their professor urged them to consider carefully the very fine balance between work and life's other commitments. He said, "*imagine life as a juggling game, keeping five balls in the air. The five balls represent work, family, health, friends and spirit. You will soon recognise that work is represented by a rubber ball. If it should fall, it will immediately bounce back. However, the remaining four balls are made of crystal. If any of these should fall they will become irrevocably damaged. Try to understand the complexity of this, and strive to achieve the perfect balance for your lives*".

MCDM, and the GP approach in particular provides a good visual representation of "these juggling balls". In this study, these balls are represented by social, economic and environmental goals, which are all decision-making factors in farming systems and which are all potentially capable of being damaged beyond repair. By introducing a new technology, this study has shown that if we were to consider only the impact on a single aspect whilst neglecting others, we may run the risk of not being able to observe or monitor impacts on other factors. Above all else, what the model results and sensitivity analysis showed is that aspects of the farming system can be highly sensitive to changes or the weight of any of these 3 balls.

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Appendix 1.1
Pesticides use by EU country

COUNTRY:	ITALY		
Variety:	All		
Fungicides			
PRODUCT	kg/ha	%AI	kgAI/ha
Copper oxy.	10.00	0.50	5.00
Dithane	48.00	0.80	38.40
Anvil	1.40	0.05	0.07
Saprol	8.00	0.19	1.52
total			**44.99**
Insecticides			
Metasistox	3.00	0.25	0.75
Nomolt	0.60	0.15	0.09
Brution	5.00	0.42	2.10
Gusathion	16.00	0.85	13.60
total			**16.54**
Others			
Carbaryl	2.50	0.45	1.13
total			**1.13**

COUNTRY:	FRANCE		
Variety:	All		
Fungicides			
Sulphur	40	0.80	32.00
TMTD	7.5	0.8	6.00
Captan	10	0.83	8.30
Ditahne	10	0.8	8.00
Bayleton	2	0.25	0.50
Thiovit	44	0.8	35.20
Benlate	2	0.5	1.00
Mikal	6	0.75	4.50
Sandomil	2	0.45	0.90
Copper oxy.	26	0.082	2.13
total			**98.53**
Insecticides			
Gusathion MS	2.00	0.85	1.70
Lannate 20L	4.00	0.20	0.80
Kilval	1.30	0.40	0.52
AzinugecPM	2.00	0.50	1.00
Cesar 100	0.50	0.10	
Ultracide	2.00	0.40	0.80
Dichrolvos	6.00	0.50	3.00
total			**7.82**
Herbicides			
Aminotriazole	6.50	0.23	1.46
Basta	1.30	0.15	0.20
Simazine	3.00	0.50	1.50
2-4-D	1.25	0.50	0.63
total			**3.78**
Others			
NAD	1	0.036	0.04
ANA	2	0.058	0.12
			0.15

COUNTRY:	FRANCE		
Variety:	Golden Delicious		
Fungicides			
Ziram	2.88	0.32	0.92
TMTD	9.48	0.8	7.58
Captan	6.16	0.83	5.11
Dithane	6.64	0.8	5.31
Bayleton	0.13	0.25	0.03
Topaz	1.14	0.1	0.11
Quinolate	0.51	0.4	0.20
Triforine	0.05	0.19	0.01
Copper	11.63	0.05	0.58
Dolan	0.24	0.25	0.06
Sulfur	21.23	0.8	16.98
total			**36.92**
Insecticides			
Amitraz	0.63	0.85	0.54
Zolone	0.50	0.20	0.10
Kilval	0.52	0.40	0.21
Ovipron	7.21	0.50	3.61
Omite	1.08	0.25	0.27
Methidation	2.00	0.40	0.80
Dichrolvos	6.00	0.50	3.00
total			**8.52**
Herbicides			
Paraquat	6.50	0.20	1.30
Basta	0.92	0.36	0.33
Gallup	0.60	0.36	0.22
2-4-D	1.25	0.50	0.63
total			**2.47**
Others			
NAD	1	0.036	0.04
ANA	2	0.058	0.12
			0.15

COUNTRY:	PORTUGAL		
Variety:	All		
Region: Centre			
Fungicides			
Dodine	0.5	0.45	0.23
Rubigan	0.5	0.12	0.06
Dithane	12.5	0.8	10.00
Benlate	0.6	0.5	0.30
Copper oxy.	7.5	0.5	3.75
total			**14.34**
Insecticides			
Gusathion	6.00	0.85	5.10
TCHE	4.80		
Ultracide	2.00	0.40	0.80
Parathion	30.00		
total			**5.90**

Source:Ministry of Agriculture R.I.C.A.

COUNTRY:	PORTUGAL		
Variety:	All		
Region: Lisboa e Vale do Tejo			
Fungicides			
Dinocap	1.2	0.35	0.42
Dithane	10	0.8	8.00
Copper oxy.	12	0.5	6.00
total			**14.42**
Insecticides			
Dimethoate	3.00	0.40	1.20
Dicofol+Tetradifon	3.00	0.25	0.75
total			**1.95**
Herbicides			
Paraquat	3.00	0.20	0.60
total			**0.60**

Source:Ministry of Agriculture R.I.C.A.

COUNTRY:	UK		
Variety:	Cox'Orange		
Fungicides			
Dithianon	2.2	0.75	1.65
Captan	9.8	0.80	7.84
Pyrifenox	1.8	0.2	0.36
Bupirimate	4.4	0.25	1.10
total			**10.95**
Insecticides			
Lorsban	3.00	0.48	1.44
Pomex	8.20	0.50	4.10
total			**5.54**
Herbicides			
Dicamba +	5	0.215	1.08
Amitrole	5	0.225	1.13
Simazine	1.7	0.5	0.85
Diuron	1.00	0.50	0.50
total			**3.55**

Source ADAS

Variety:	Bramley		
Fungicides			
Dithianon	6.2	0.75	4.65
Dithane	5.4	0.75	4.05
Pyrifenox	1.8	0.2	0.36
total			**9.06**
Insecticides			
Lorsban	3.00	0.48	1.44
Pomex	8.60	0.50	4.30
total			**5.74**
Herbicides			
Dicamba +	5	0.215	1.08
Diquat+Para.	5.5	0.2	1.10
Amitrole	5	0.225	1.13
Simazine	2.2	0.5	1.10
Diuron	2.00	0.50	1.00
total			**5.40**

Source ADAS

COUNTRY:	**SPAIN**		
Variety:	All		
Region:	Cataluna		
Production years: 7-15			
Fungicides			
Captan	22.5	0.50	11.25
Folpet	4	0.80	3.20
Atemi	0.4	0.05	0.02
DNCO	30	0.05	1.50
Sulphur	35	0.8	28.00
Copper oxy.	20	0.5	10.00
total			**53.97**
Insecticides			
Gusathion	11.25	0.20	2.25
Dimetoato	4.00	0.40	1.60
Mecarban	2.00	0.50	1.00
total			**4.85**
Herbicides			
Roundup	2.1	0.36	0.76
Basta	2.55	0.15	0.38
Simazine	1.4	0.5	0.70
total			**1.84**
Others			
Promalin	1	0.038	0.04
ANA	1.2	0.01	0.01
			0.05

Source Co-operative COSTA BRAVA

COUNTRY:	**SPAIN**		
Variety:	All		
Region:	Aragon		
Production years: 7-15			
Fungicides			
Captan	7.5	0.50	3.75
Sulphur	30	0.80	24.00
Bayfidan	0.3	0.25	0.08
DNCO	30	0.05	1.50
total			**29.33**
Insecticides			
Dimethoato	3.75	0.40	1.50
Confidor	0.50	0.70	0.35
Gusathion	7.00	0.20	1.40
Insegar	0.40	0.25	0.10
Zolone	2.00	0.35	0.70
Fenitrothion	1.50	0.50	0.75
total			**4.93**
Herbicides			
Roundup	2.8	0.36	1.01
Stomp	4.5	0.4	1.80
Simazine	1.4	0.5	0.70
total			**3.51**
Others			
Promalin	0.3	0.038	0.01
ANA	1.25	0.01	0.01
total			**0.02**

Source Co-operative COSANSE

COUNTRY:	SPAIN		
Variety:	All		
Region:	Cataluna	(Lerida)	
Production years: 7-15			
Fungicides			
Captan	7.5	0.50	3.75
Sulphur	30	0.80	24.00
Bayfidan	0.3	0.25	0.08
DNCO	30	0.05	1.50
total			**29.33**
Insecticides			
Dimethoato	3.75	0.40	1.50
Condifor	0.50	0.70	0.35
Gusathion	7.00	0.20	1.40
Insegar	0.40	0.25	0.10
Zolone	2.00	0.35	0.70
Dimilin	0.50	0.25	0.13
Fenitrothion	1.50	0.50	0.75
total			**4.93**
Herbicides			
Roundup	2.8	0.36	1.01
Stomp	4.5	0.4	1.80
Simazine	1.4	0.5	0.70
total			**3.51**
Others			
Promalin	0.3	0.038	0.01
ANA	1.25	0.01	0.01
total			**0.02**

Source Co-operative ACTEL

COUNTRY:NETHERLANDS			
Variety:	All		
Region:	All		
Production years: 7-15			
Fungicides			
Copper 500wp	6	0.50	3.00
Benomyl 500wp	1	0.50	0.50
Captan 500sc	3	0.50	1.50
Bayleton 050wp	1	0.05	0.05
Nimrod 250wp	0.5	0.25	0.13
Baycor 250wp	1.5	0.25	0.38
Delan 750 sc	1.5	0.75	1.13
total			**6.68**
Insecticides			
Zolone 500sc	1.20	0.50	0.60
Dimilin 480sc	0.75	0.48	0.36
Ultracid 400wp	1.00	0.40	0.40
Dimethoate 400ec	2.00	0.40	0.80
Pirimor 500wg	0.50	0.50	0.25
Apollo 500sc	1.00	0.50	0.50
Insegar 250wp	0.30	0.25	0.08
total			**2.99**
Herbicides			
Glyphosate 360sl	5	0.36	1.80
Diuron 800wp	3	0.8	2.40
Simazine 500sc	3	0.5	1.50

Paraquat 200sl	4	0.2	0.80
total			**6.50**

Others

Carbaryl 500wp	0.15	0.5	0.08
Fruitone na 100li	0.1	0.1	0.01
Gibbereline	0.25	0	0.00
Obsthormon	0.15	0	0.00
total			**0.09**

Source Landell Mills Market Research LTD

COUNTRY:	**DENMARK**
Variety:	All
Region:	All
Production years: 7-15	

Fungicides

Baycor 300ec	1	0.30	0.30
Benlate 500wp	1.2	0.50	0.60
Cadol 250li	4	0.25	1.00
Captan 830wp	3	0.83	2.49
Sulphur 800wp	12	0.80	9.60
total			**13.99**

Insecticides

Cypermethrin 100li	0.50	0.10	0.05
Decis 025li	0.30	0.03	0.01
Dimecron 500li	1.00	0.50	0.50
Fastac 100ec	0.20	0.10	0.02
Gusathion 250wp	1.00	0.25	0.25
Metox 100ec	2.00	0.10	0.20
Apollo 500sc	0.50	0.50	0.25
Kelthane 300ec	1.00	0.30	0.30
Mitac 215li	1.00	0.22	0.22
Nissorun 100ec	0.50	0.10	0.05
Torque 500li	0.50	0.50	0.25
Pirimor 500wp	0.30	0.50	0.15
total			**2.24**

Source Landell Mills Market Research LTD

COUNTRY:	**GERMANY**
Variety:	All
Region:	All
Production years: 7-15	

Fungicides

Delan	5	0.75	3.75
Bayfidan	0.5	0.05	0.03
Rubigan sc	0.6	0.12	0.07
Benocap	0.25	0.20	0.05
Omnex	0.5	0.63	0.31
Dithane	2	0.80	1.60
Euparen	3	0.50	1.50
Benomyl	0.3	0.50	0.15
total			**7.46**

Insecticides

Rubitox	1.00	0.35	0.35
Insegar	0.40	0.25	0.10
Metasystox	0.25	0.30	0.08
Pirimor	0.50	0.50	0.25
Apollo	0.08	0.50	0.04
Torque	0.40	0.50	0.20

Dimilin	0.50	0.25	0.13
total			**1.14**
Herbicides			
Round up	1	0.36	0.36
Basta	1.5	0.2	0.30
total			**0.66**
Others			
Amid-Thin 084wp	0.08	0.084	0.01
Aperdex 400wt	0.03	0.4	0.01
Carbaryl 500wp	0.15	0.5	0.08
Fruitone na 100li	0.1	0.1	0.01
Gibbereline	0.25	0	0.00
Obsthormon	0.15	0	0.00
total			**0.10**

Source: Dr. Bernhard Sessler (not published)

COUNTRY: **GREECE**
Variety: All
Region: All
Production years: 7-15

Fungicides			
Delan	5.04	0.75	3.78
Systhane 125	2	0.13	0.25
Ri midin	2	0.06	0.12
Melprex	3	0.68	2.03
Captan	15	0.50	7.50
Dithane	4	0.80	3.20
Baycor	2	0.25	0.50
Cu	10	0.50	5.00
total			**22.38**
Insecticides			
Zolone	2.80	0.35	0.98
Dimilin	0.50	0.25	0.13
Guzathion	1.00	0.40	0.40
Imidan	4.00	0.50	2.00
Apollo	0.50	0.50	0.25
Omite	4.00	0.30	1.20
Ultracide	4.20	0.40	1.68
Alsystin	2.50	0.25	0.63
total			**7.26**
Herbicides			
Round up	3	0.36	1.08
Basta	1	0.2	0.20
total			**1.28**

Source: Landell Mills LTD and University of Thessaloniki

COUNTRY: **BELGIUM**
Variety: All
Region: All
Production years: 7-15

Fungicides			
Mancozeb	4	0.80	3.20
Baycor	1	0.25	0.25
Euparen	1	0.50	0.50
Bayleton	0.5	0.25	0.13
Ronilan	0.5	0.50	0.25
Captan	2	0.83	1.66

Cu	4	0.50	2.00
Polyram Combi	3	0.80	2.40
total			**10.39**
Insecticides			
DNOC	2.50	0.56	1.40
Decis 025	0.30	0.03	0.01
Dimilin	0.60	0.25	0.15
Insegar 250	0.30	0.25	0.08
Apollo	0.40	0.50	0.20
Nissorum 100	0.04	0.10	0.00
total			**1.84**
Herbicides			
Basta	5	0.2	1.00
Roundup 360	2.8	0.36	1.01
Simazine 500	2	0.5	1.00
total			**3.01**
Others			
Ethephon 480	0.15	0.48	0.07
total			**0.07**

Source: Landell Mills LTD and

Appendix 3.1
Weighted value and use of pesticide by EU country.

COUNTRY:	ITALY						
Variety	All	Source:Confcooperative		Region: Emilia Romagna			
	1	2	3	4	5	6	7
PRODUCT	**kg/ha**	**%AI**	**kgAI/ha**	**%**	**ECU/kg**	**ECU/AI**	**4*6**
Fungicides							
Copper oxy.	10.00	0.50	5.00	11.11	2.71	5.42	0.60
Mancozeb	48.00	0.80	38.40	85.35	4.45	5.56	4.75
Hexaconazole	1.40	0.05	0.07	0.16	23.11	462.20	0.72
Saprol	8.00	0.19	1.52	3.38	19.25	101.32	3.42
total			**44.99**				**9.49**
Insecticides							
Oxidemeton	3.00	0.25	0.75	4.53	21.37	85.48	3.88
Teflubenzuron	0.60	0.15	0.09	0.54	118.43	789.53	4.30
Methidathion	5.00	0.42	2.10	12.70	10.22	24.33	3.09
Azinphos-M	16.00	0.85	13.60	82.22	6.50	7.65	6.29
total			**16.54**				**17.55**
Others							
Carbaryl	2.50	0.45	1.13	100.00	4.85	10.78	10.78
			1.13				**10.78**

COUNTRY:	FRANCE		Source: Centre D'Economie Rurale de Tarn & Garonne				
Variety:	All						
Fungicides							
Sulphur	40	0.80	32.00	32.48	1.22	1.52	0.49
Thiram	7.5	0.8	6.00	6.09	3.81	4.76	0.29
Captan	10	0.83	8.30	8.42	5.33	6.42	0.54
Mancozeb	10	0.8	8.00	8.12	3.65	4.57	0.37
Triadimefon	2	0.25	0.50	0.51	8.52	34.10	0.17
Thiovit	44	0.8	35.20	35.72	1.20	1.50	0.54
Benomyl	2	0.5	1.00	1.01	24.96	49.92	0.51
Mikal	6	0.75	4.50	4.57	9.74	12.99	0.59
Sandomil	2	0.45	0.90	0.91	9.74	21.65	0.20
Copper oxy.	26	0.082	2.13	2.16	3.10	37.80	0.82
total			**98.53**				**4.52**
Insecticides							
Azinphox-M	2.00	0.85	1.70	21.74	13.39	15.76	3.43
Lannate 20L	4.00	0.20	0.80	10.23	12.79	63.93	6.54
Vamidothion	1.30	0.40	0.52	6.65	18.72	46.80	3.11
AzinugecPM	2.00	0.50	1.00	12.79	4.87	9.74	1.25
Hexythiazox	0.50	0.10			83.11		
Methidathion	2.00	0.40	0.80	10.23	11.42	28.54	2.92
Dichrolvos	6.00	0.50	3.00	38.36	7.46	14.92	5.72
total			**7.82**				**22.97**
Herbicides							
Aminotriazole	6.50	0.23	1.46	38.66	4.11	18.27	7.06
Glufosinate	1.30	0.15	0.20	5.16	8.62	57.48	2.96
Simazine	3.00	0.50	1.50	39.66	3.35	6.70	2.66
2-4-D	1.25	0.50	0.63	16.52	3.54	7.08	1.17
total			**3.78**				**13.85**
Others							
NAD	1	0.036	0.04	23.68	25.11	697.63	165.23
ANA	2	0.058	0.12	76.32	8.68	149.59	114.16
			0.15				**279.39**

COUNTRY:	FRANCE		Source: CEMAGEF				
Variety:	Golden Delicious		Region: Loiret				
	1	2	3	4	5	6	7
PRODUCT	kg/ha	%AI	kgAI/ha	%	ECU/kg	ECU/AI	4*6
Fungicides							
Ziram	2.88	0.32	0.92	2.50	2.12	6.63	0.17
Thiram	9.48	0.8	7.58	20.54	2.02	2.53	0.52
Captan	6.16	0.83	5.11	13.85	4.57	5.51	0.76
Mancozeb	6.64	0.8	5.31	14.39	3.43	4.29	0.62
Triadimefon	0.13	0.25	0.03	0.09	8.86	35.44	0.03
Penconazole	1.14	0.1	0.11	0.31	15.95	159.50	0.49
Quinolate	0.51	0.4	0.20	0.55	17.09	42.73	0.24
Triforine	0.05	0.19	0.01	0.03	9.33	49.11	0.01
Copper	11.63	0.05	0.58	1.58	1.60	32.00	0.50
Dithianon	0.24	0.25	0.06	0.16	18.73	74.92	0.12
Sulfur	21.23	0.8	16.98	46.01	1.00	1.25	0.58
total			**36.92**	**100.00**			**4.04**
Insecticides							
Amitraz	0.63	0.85	0.54	6.29	20.16	23.72	1.49
Zolone	0.50	0.20	0.10	1.17	14.47	72.35	0.85
Kilval	0.52	0.40	0.21	2.44	14.45	36.13	0.88
Ovipron	7.21	0.50	3.61	42.32	2.05	4.10	1.74
Propargite	1.08	0.25	0.27	3.17	11.02	44.08	1.40
Ultracide	2.00	0.40	0.80	9.39	11.42	28.54	2.68
Dichrolvos	6.00	0.50	3.00	35.22	7.46	14.92	5.25
total			**8.52**	**100.00**			**14.29**
Herbicides							
Paraquat	6.50	0.20	1.30	52.58	11.45	57.25	30.10
Glufosinate	0.92	0.36	0.33	13.40	8.62	23.95	3.21
Gallup	0.60	0.36	0.22	8.74	3.56	9.89	0.86
2-4-D	1.25	0.50	0.63	25.28	2.36	4.72	1.19
total			**2.47**	**100.00**			**35.37**
Others							
NAD	1	0.036	0.04	23.68	25.11	697.63	165.23
ANA	2	0.058	0.12	76.32	8.68	149.59	114.16
			0.15				**279.39**

COUNTRY: SPAIN			Source Co-operative COSTA BRAVA				
Variety: All							
Region: Cataluna							
Production years: 7-15							
	1	2	3	4	5	6	7
PRODUCT	**kg/ha**	**%AI**	**kgAI/ha**	**%**	**ECU/kg**	**ECU/AI**	**4*6**
Fungicides							
Captan	22.5	0.50	11.25	20.84	2.89	5.78	1.20
Folpet	4	0.80	3.20	5.93	3.23	4.04	0.24
Ciproconazole	0.4	0.05	0.02	0.04	61.55	1231.00	0.46
DNCO	30	0.05	1.50	2.78	0.77	15.40	0.43
Sulphur	35	0.8	28.00	51.88	0.77	0.96	0.50
Copper oxy.	20	0.5	10.00	18.53	1.85	3.70	0.69
total			**53.97**				**3.51**
Insecticides							
Azinphox-M	11.25	0.20	2.25	46.39	3.54	17.70	8.21
Dimethoathe	4.00	0.40	1.60	32.99	3.08	7.70	2.54
Mecarban	2.00	0.50	1.00	20.62	15.39	30.78	6.35
total			**4.85**				**17.10**
Herbicides							
Glyphosate	2.1	0.36	0.76	41.12	6.15	17.08	7.02
Glufosinato	2.55	0.15	0.38	20.81	9.23	61.53	12.80
Simazine	1.4	0.5	0.70	38.07	3.08	6.16	2.35
total			**1.84**				**22.17**
Others							
Promalin	1	0.038	0.04	76.00	203.12	5345.26	4062.40
ANA	1.2	0.01	0.01	24.00	6.15	615.00	147.60
			0.05				**4210.00**

COUNTRY: SPAIN			Source Co-operative COSANSE				
Variety: All							
Region: Aragon							
Production years: 7-15							
Fungicides							
Captan	7.5	0.50	3.75	12.79	2.89	5.78	0.74
Sulphur	30	0.80	24.00	81.84	0.77	0.96	0.79
Triadimenol	0.3	0.25	0.08	0.26	58.47	233.88	0.60
DNCO	30	0.05	1.50	5.12	0.77	15.40	0.79
total			**29.33**				**2.91**
Insecticides							
Dimethoathe	3.75	0.40	1.50	30.46	3.08	7.70	2.35
Imidacloprid	0.50	0.70	0.35	7.11	64.63	92.33	6.56
Azinphox-M	7.00	0.20	1.40	28.43	3.54	17.70	5.03
Fenoxicarb	0.40	0.25	0.10	2.03	97.46	389.84	7.92
Phosalone	2.00	0.35	0.70	14.21	8.62	24.63	3.50
Diflubensuron	0.50	0.25	0.13	2.54	65.24	260.96	6.62
Fenitrothion	1.50	0.50	0.75	15.23	5.42	10.84	1.65
total			**4.93**				**33.63**
Herbicides							
Glifosate	2.8	0.36	1.01	28.73	5.53	15.36	4.41
Pendimethalin	4.5	0.4	1.80	51.31	9.23	23.08	11.84
Simazine	1.4	0.5	0.70	19.95	3.08	6.16	1.23
total			**3.51**				**17.48**
Others							
Promalin	0.3	0.038	0.01	47.70	203.12	5345.26	2549.62
ANA	1.25	0.01	0.01	52.30	6.15	615.00	321.65
			0.02				**2871.28**

COUNTRY:	SPAIN		Source Co-operative ACTEL				
Variety:	All						
Region:	Cataluna	(Lerida)					
Production years: 7-15							
	1	2	3	4	5	6	7
PRODUCT	**kg/ha**	%AI	**kgAI/ha**	%	**ECU/kg**	**ECU/AI**	**4*6**
Fungicides							
Captan	7.5	0.50	3.75	12.79	2.89	5.78	0.74
Sulphur	30	0.80	24.00	81.84	0.77	0.96	0.79
Triadimenol	0.3	0.25	0.08	0.26	58.47	233.88	0.60
DNCO	30	0.05	1.50	5.12	0.77	15.40	0.79
total			**29.33**				**2.91**
Insecticides							
Dimethoathe	3.75	0.40	1.50	30.46	3.08	7.70	2.35
Imidacloprid	0.50	0.70	0.35	7.11	64.63	92.33	6.56
Azinphoz-M	7.00	0.20	1.40	28.43	3.54	17.70	5.03
Fenoxicarb	0.40	0.25	0.10	2.03	97.46	389.84	7.92
Phosalone	2.00	0.35	0.70	14.21	8.62	24.63	3.50
Diflubenzuron	0.50	0.25	0.13	2.54	65.24	260.96	6.62
Fenitrothion	1.50	0.50	0.75	15.23	5.42	10.84	1.65
total			**4.93**				**33.63**
Herbicides							
Glyfosate	2.8	0.36	1.01	28.73	5.53	15.36	4.41
Pendimethalin	4.5	0.4	1.80	51.31	9.23	23.08	11.84
Simazine	1.4	0.5	0.70	19.95	3.08	6.16	1.23
total			**3.51**				**17.48**
Others							
Promalin	0.3	0.038	0.01	47.70	203.12	5345.26	2549.62
ANA	1.25	0.01	0.01	52.30	6.15	615.00	321.65
			0.02				**2871.28**

COUNTRY:	GERMANY	Source: Dr. Bernhard Sessler (not published)					
Variety:	All						
Region:	All						
Production years: 7-15							
	1	2	3	4	5	6	7
PRODUCT	kg/ha	%AI	kgAI/ha	%	ECU/kg	ECU/AI	4*6
Fungicides							
Dithianon	5	0.75	3.75	50.27	48.17	64.22	32.28
Triadimenol	0.5	0.05	0.03	0.34	20.94	418.83	1.40
Fenarimol	0.6	0.12	0.07	0.97	91.62	763.50	7.37
Flusilazole	0.25	0.20	0.05	0.67	176.96	884.78	5.93
Mancozeb+Penc	0.5	0.63	0.31	4.19	65.44	104.71	4.39
Mancozeb	2	0.80	1.60	21.45	9.95	12.43	2.67
Dichlofluanid	3	0.50	1.50	20.11	23.56	47.12	9.47
Benomyl	0.3	0.50	0.15	2.01	91.62	183.24	3.68
total			**7.46**	**100.00**			**67.20**
Insecticides							
Phosalone	1.00	0.35	0.35	30.77	23.56	67.31	20.71
Fenoxycarb	0.40	0.25	0.10	8.79	141.36	565.42	49.71
Oxydemeton-M	0.25	0.30	0.08	6.59	32.46	108.20	7.13
Pirimicarb	0.50	0.50	0.25	21.98	81.15	162.30	35.67
Clofentezine	0.08	0.50	0.04	3.30	256.01	512.02	16.88
Fenbutatin	0.40	0.50	0.20	17.58	83.77	167.53	29.46
Diflubenzuron	0.50	0.25	0.13	10.99	115.18	460.72	50.63
total			**1.14**	**100.00**			**210.19**
Herbicides							
Glyphosate	1	0.36	0.36	54.55	24.60643	68.35	37.28
Glufosinate	1.5	0.2	0.30	45.45	25.12997	125.65	57.11
total			**0.66**	100.00			**94.40**
Others							
Amid-Thin	0.08	0.084	0.01	7.91	37.85202	450.62	35.63
Aperdex 400wt	0.03	0.4	0.01	14.12	4.078385	10.20	1.44
Carbaryl	0.15	0.5	0.08	88.24	15.33975	30.68	27.07
Fruitone na 100li	0.1	0.1	0.01	11.76	10.09911	100.99	11.88
Gibbereline	0.25	0	0.00	0.00	155.5493	0.00	0.00
Obsthormon	0.15	0	0.00	0.00	62.90345	0.00	0.00
total			**0.10**	122.02			**76.02**

COUNTRY:	GREECE		Source: Landell Mills LTD and University of Thessaloniki				
Variety:	All						
Region:	All						
Production years: 7-15							
	1	2	3	4	5	6	7
PRODUCT	**kg/ha**	**%AI**	**kgAI/ha**	**%**	**ECU/kg**	**ECU/AI**	**4*6**
Fungicides							
Dithianon	5.04	0.75	3.78	16.89	38.17	50.90	8.60
Myclobutanil	2	0.13	0.25	1.12	38.41	307.31	3.43
Fenarimol	2	0.06	0.12	0.54	22.64	377.30	2.02
Dodine	3	0.68	2.03	9.05	19.46	28.83	2.61
Captan	15	0.50	7.50	33.52	7.14	14.27	4.78
Mancozeb	4	0.80	3.20	14.30	7.38	9.22	1.32
Bitertanol	2	0.25	0.50	2.23	31.86	127.43	2.85
Cu	10	0.50	5.00	22.35	3.79	7.58	1.69
total			**22.38**	**100.00**			**27.31**
Insecticides							
Phosalone	2.80	0.35	0.98	13.50	39.40	112.56	15.19
Diflubenzuron	0.50	0.25	0.13	1.72	87.28	349.10	6.01
Azonfos-M	1.00	0.40	0.40	5.51	12.43	31.07	1.71
Phosmet	4.00	0.50	2.00	27.55	14.61	29.23	8.05
Clofentezine	0.50	0.50	0.25	3.44	150.51	301.02	10.37
Propargite	4.00	0.30	1.20	16.53	15.02	50.08	8.28
Methidathion	4.20	0.40	1.68	23.14	20.69	51.73	11.97
Triflumuron	2.50	0.25	0.63	8.61	102.74	410.97	35.38
total			**7.26**	**100.00**			**96.96**
Herbicides							
Glyfosate	3	0.36	1.08	163.64	16.15068	44.86	73.41
Glufosinate	1	0.2	0.20	30.30	11.95082	59.75	18.11
total			**1.28**	193.94			**91.52**

Appendix 3.3

Environmental Impact Quotient (EIQ) values for herbicides.

Farm-workers (EIQ P), Consumers (EIQ C) and the Ecological (EIQ E) components.

Product	Trade Name	EIQ P	EIQ C	EIQ E	EIQ Total
2,4-D(acid)	Weedone	72	9	88	169
acifluorfen	Blazer	72	12	72	156
alachlor	Lasso	18	6	40	64
ammonium sulfamate	Ammate	24	8	83	115
atrazine	Atrazine	12	9.5	78	99.5
bentazon	Basagran 4S	24	11	81	116
bromacil	Hyvar	12	11	54	77
chloramben	Amiben	15	5.5	26.6	47.1
cyanazine	Bladex	26	7.3	26	59.3
cycloate	Ro-Neet	6	5	35	46
dalapon	Dalapon	36	8	68.5	112.5
DCPA	Dacthal	16	9	77	102
dichlobenil	Casoron	18	7	29	54
diethatyl-ethyl	Antor	6	3	35	44
diuron	Karmex	15	10.5	36	61.5
EPTC	Eptam	6	5	29	40
ethalfluralin	Sonolan	30	11	51	92
fluazifop-butyl	Fusilade	40	11	81	132
glyphosate	Roundup	16	7	74.3	97.3
linuron	Lorox	16	9	96	121
MCPA	Bronate	32	9	69	110
metholachlor	Dual	12	7	35	54
metribuzim	Sencor	8	8	90	106
napropamide	Devrinol	12.8	9.3	32	54.1
nicosulfuron	Accent	12	5	69.6	86.6
norflurazon	Solicam	9	9.5	38	56.5
oryzalin	Surflan	12	3	38	53
oxyfluorfen	Goal	20	8.5	112	140.5
paraquat	Gramoxone	72	13	125	210
pendimethalin	Prowl	15	8.5	54	77.5
phenmediphan	Spin-aid	12	5.5	74.6	92.1
pronamide	Kerb	24	10	74	108
propazine	Milogard	24	17	75	116
pryazon	Pyramin	6	7	35	48
sethoxydim	Poast	8	4.9	69.6	82.5
simizine	Princep	12	9	26.2	47.2
tebacil	Sinbar	12	11	27.5	50.5
trifluralin	Treflan	15	8.5	57	80.5

Environmental Impact Quotient (EIQ) values for fungicides and nematicides.

Product	Trade Name	EIQ P	EIQ C	EIQ E	EIQ Total
anilizaine	Dyrene	16.2	5.1	58.7	80
benomyl	Benlate	30	50	128.5	208.5
captan	Orthocide	28	8	49.9	85.9
carboxin	Vitavax	9	5.5	45.4	59.9
chlorothalonil	Bravo	25	11	102	138
copper hydroxide	Kocide	12.2	5.1	82.7	100
copper sulfate+lime	Copper	81	14.5	47.9	143.4
copper sulfate+lime	Bordeaux	108	19	76	203
dichloran	Botran	24.3	7.2	76.4	107.9
dinocap	Karathane	22	12	36.9	70.9
dodine	Syllit	20.3	16.4	67.9	104.6
fenarimol	Rubigan	12	23	47	82
fentin hydroxide	Du-Ter	24	5	69	98
ferban	Carbamate	8	5	73.5	86.5
flusilazol	Nustar	8	9	81.8	98.8
folpet	Phaltan	8.1	5.7	52.9	66.7
fosetyl- Al	Aliette	12	7	22	41
iprodione	Rovral	8.1	3.1	68.7	79.9
mancozeb	Manzate	40	17	130	187
maneb+dinocap	Maneb	40	17	135.3	192.3
maneb+dinocap	Dikar	32.4	13.2	93.9	139.5
matalaxyl	Ridomil	8	11	68.5	87.5
metiram	Polyram	50	16	101.8	167.8
myclobutanil	Nova	36.5	13.8	73.4	123.7
PCNB	Terraclor	15	8.5	42	65.5
streptomycin	Agristrep	18	4.6	33.5	56.1
sulfur	Sulfur	10	6	120	136
thiophanate methyl	Topsin-M	30	28	96.5	154.5
thiram	Thiram	72.9	7.2	83.5	163.6
triadmefon	Bayleton	28	10	62	100
triforine	Fumginex	24.3	25.9	73.4	123.6
vinclozolin	Ronilan	24.3	7.2	56.7	88.2
zineb	Dithane Z	40	23	68.9	131.9

Environmental Impact Quotient (EIQ) values for insecticides.

Product	Trade Name	EIQ P	EIQ C	EIQ E	EIQ Total
disulfoton	Di-Syston	150	28	187.8	365.8
parathion	Niran-Phoskil	140	8	165.1	313.1
oxidemeton-methyl	Metasystox-R	96	29	122.6	247.6
carbofuran	Furadan	72	29	69.4	170.4
dimethoate	Cygon	72	9	140.9	221.9
propoxur	Baygon	72	13	176.8	261.8
dichlorvos	Vapona	60	3	58.8	121.8
methidathion	Supracide	60	8	139.8	207.8
ethropop	Mocap	57.5	9.1	67.2	133.8
methyl parathion	Penncap-M	54	4	47.7	105.7
naled	Dibrom	54	4	55	113
rotenone	Chem-fish	54	4	41	99
ryania	Ryania	45.6	7	113.3	165.9
aldicarb	Temik	45	14	52.4	111.4
chlorpyrifos	Lorsban	45	8.5	104.9	158.4
fonofos	Dyfonate	45	6	82.8	133.8
fensulfothion	Dasanit	40	14	146.6	200.6
methamidophos	Monitor	40	11	141.3	192.3
phorate	Thimet	40	10	154.6	204.6
propargite	Omite	40	6	82.2	128.2
sabadilla	Red Devil	39.3	6	61.6	106.9
azinphos-metil	Guthion	36	5	88.3	129.3
dicofol	Kelthane	36	5	48.6	89.6
endosulfan	Thiodan	36	7	78.6	121.6
ethion	Ethion	34.5	2.5	86.2	123.2
pirimicarb	Pirimor	34.2	11.4	45.9	91.5
mevinphos	Phosdrin	30	6	48.5	84.5
piperonyl butoxide	Butacide	30	3.7	28.7	62.4
terbufos	Counter	30	4	62.8	96.8
methoxychlor	Marlate	25	13.5	135.5	174
malathion	Cythion	21	4.5	44	69.5
permethrin	Ambush	20	8.5	140.8	169.3
phosphamidon	Swat	18	8	52.9	78.9
oxythioquinox	Morestan	16	7	110.1	133.1
diazinon	Diazinon	15	8	79.5	102.5
diflubenzuron	Dimilin	15	5.5	98	118.5
oxamyl	Vydate	15	8.5	45.2	68.7
cryolite	Kryocide	13.1	6	45.2	64.3
bacillus thuringiensis	Dipel	12	6	22.5	40.5
carbaryl	Sevin	12	3	52.7	67.7
phosmet	Imidan	12	3	56.7	71.7
soap	M-Pede	11.4	5.1	41.8	58.3
esfenvalerate	Asana	8	4	136.8	148.8
fenvalerate	Pydrin	8	4	136.8	148.8
oil	Oil	8	3.7	71	82.7

Appendix 3.4

The Model code identification

The Goal Programming model consists of constraints, variables, goals and the objective function. For each constraint the model was assigned a specific code identified by no more than 8 characters. Code identification is as follows:

The first character represents the activity.

S: Storage

D: Demand at the domestic market

E: Exports to extra European union countries

I: Imports from extra European union countries

ID: Apples for industry

W: Wastage

The second digit in the code represents the European Union Countries.

G: Greece

I: Italy

F: France

GY: Germany

S: Spain

The third and fourth characters account for the different varieties:

GD: Golden Delicious

RD: Red Delicious

JG: Jonagold

BK: Boskoop

IM: Imperatore Rome

GS: Granny Smith

CX: Cox's Orange

BM: Brambly

GL: Gloster

OT: Others

AV: All varieties

NV: New varieties

The last character corresponds to the month:

A: January

B: February

C: March

D: April

E: May

F: June

G: July

H: August

I: September

J: October

K: November

L: December.

Inputs are represented by the following letters:

P: Phosphorus

N: Nitrogen

K: Potassium

I: Insecticides

F: Fungicides

H: Herbicides

O: Others pesticides

HV: Labour for harvesting

PR: Labour for pruning

OT: Others activities which demand labour

L: Land use

With regard to the environmental variables and constraints:

X: Environmental activities and constraints

P: Farm workers

C: Consumers

E: Environment

Finally, in some codes the model is assigned numbers, in order to represent region within a country. This is based on the NUTS-2 area of land classification; i.e. 1 = NUTS 1, 2 = NUTS 2 and so on.

Example:

The constraint SSRDL corresponds to red delicious apples from Spain stored during December

S1GDHV corresponds to the amount of labour hours needed for harvesting Golden Delicious in NUTS 1 in Spain).

For the different activities we have used the same criterion.

Lastly Goals and deviational variables have been defined.

Goals are represented by the following form;

UI: Income

POL: Level of pollution

LAB: Labour

With regard to deviational variables we have both positive and negative variables:

N: Negatives Deviational Variables

P: Positive Deviational variables.

The number following N or P represents a specific goal. (e.g. N4;P4 means negative and positive deviational variables respectively for the goal number 4.

Appendix 5.1
Results of the GP model for the EU5 apple industry

European Union 5 countries

Current Situation	Units	Value
Land under apples	Hectares	236181.38
Golden Delicious	Hectares	105450.63
Red Delicious	Hectares	39096.51
Granny Smith	Hectares	7741.90
Jonagold	Hectares	6430.23
Boskoop	Hectares	4989.38
Gloster	Hectares	5640.84
Imperatore di Roma	Hectares	7317.89
Others	Hectares	59514.00
New Variety	Hectares	0.00
Production	Tonnes	5429547.55
Industry	Tonnes	739680.19
Income ECUs	ECUs	284596137.25
Imports from NEUC	Tonnes	227107.34
Exports from NEUC	Tonnes	2420407.48
Domestic consumption	Tonnes	5513340.15
Labour	Hours	156191048.36
EIQ Total	1	1976385520.61
EIQ P	1	475076479.75
EIQ C	1	136727851.06
EIQ E	1	1364581189.80

European Union 5 countries

Weights = 1	Units	Value
Land under apples	Hectares	46486854.14
Golden Delicious	Hectares	48602.21
Red Delicious	Hectares	24678.84
Granny Smith	Hectares	5275.070861
Jonagold	Hectares	1929.069
Boskoop	Hectares	1496.814
Gloster	Hectares	1692.252
Imperatore di Roma	Hectares	2506.97
Others	Hectares	41195.29
New Variety	Hectares	108804.87
Production	Tonnes	12064226.06
Industry	Tonnes	2321797.594
Income ECUs	ECUs	404505629.1
Imports from NEUC	Tonnes	652385442.4
Exports from NEUC	Tonnes	171699.0139
Domestic consumption	Tonnes	3615098.439
Labour	Hours	154332017.6
EIQ Total	1	1697793896
EIQ P	1	410435292.8
EIQ C	1	115021028.3
EIQ E	1	1172337575

European Union 5 countries

Weight=3 Income	Units	Value
Land under apples	Hectares	46486854.14
Golden Delicious	Hectares	55756.17132
Red Delicious	Hectares	18981.3418
Granny Smith	Hectares	9969.330304
Jonagold	Hectares	1929.069
Boskoop	Hectares	1496.814
Gloster	Hectares	1692.252
Imperatore di Roma	Hectares	4938.225505
Others	Hectares	61258.8649
New Variety	Hectares	80159.31117
Production	Tonnes	6404697.728
Industry	Tonnes	794113.0676
Income ECUs	ECUs	532419780.4
Imports from NEUC	Tonnes	227107.34
Exports from NEUC	Tonnes	174765.52
Domestic consumption	Tonnes	5565606.504
Labour	Hours	150605595.3
EIQ Total	1	1797472878
EIQ P	1	434314438.2
EIQ C	1	122658983.3
EIQ E	1	1240499457

European Union 5 countries

Weight=6 Income	Units	Value
Land under apples	Hectares	46486854.14
Golden Delicious	Hectares	61444.65565
Red Delicious	Hectares	18779.85611
Granny Smith	Hectares	11343.06741
Jonagold	Hectares	1929.069
Boskoop	Hectares	1496.814
Gloster	Hectares	1692.252
Imperatore di Roma	Hectares	4938.225505
Others	Hectares	64106.46316
New Variety	Hectares	70450.97718
Production	Tonnes	6409933.872
Industry	Tonnes	794113.0676
Income ECUs	ECUs	545725064.6
Imports from NEUC	Tonnes	227107.34
Exports from NEUC	Tonnes	174765.52
Domestic consumption	Tonnes	5573626.618
Labour	Hours	150684124.8
EIQ Total	1	1860680629
EIQ P	1	450910717.8
EIQ C	1	126860081.6
EIQ E	1	1282909830

European Union 5 countries

Weight=10 Income	**Units**	**Value**
Land under apples	Hectares	46486854.14
Golden Delicious	Hectares	63460.97504
Red Delicious	Hectares	18950.62739
Granny Smith	Hectares	11307.1863
Jonagold	Hectares	1929.069
Boskoop	Hectares	1496.814
Gloster	Hectares	1692.252
Imperatore di Roma	Hectares	4938.225505
Others	Hectares	65196.82522
New Variety	Hectares	67209.40554
Production	Tonnes	6409257.192
Industry	Tonnes	665303.0676
Income ECUs	ECUs	549308785.1
Imports from NEUC	Tonnes	227107.34
Exports from NEUC	Tonnes	174765.52
Domestic consumption	Tonnes	5574002.301
Labour	Hours	150970425.7
EIQ Total	1	1881869609
EIQ P	1	456940829.1
EIQ C	1	128219552.5
EIQ E	1	1296709227

European Union 5 countries

Weight=3 Labour	**Units**	**Value**
Land under apples	Hectares	236181.38
Golden Delicious	Hectares	39182.13098
Red Delicious	Hectares	33481.19424
Granny Smith	Hectares	4604.462369
Jonagold	Hectares	1929.069
Boskoop	Hectares	1496.814
Gloster	Hectares	1692.252
Imperatore di Roma	Hectares	2517.336529
Others	Hectares	38959.64289
New Variety	Hectares	112318.478
Production	Tonnes	6405175.506
Industry	Tonnes	794113.0676
Income ECUs	ECUs	387428355.9
Imports from NEUC	Tonnes	227107.34
Exports from NEUC	Tonnes	174765.52
Domestic consumption	Tonnes	5562621.263
Labour	Hours	155520539.1
EIQ Total	1	1670497876
EIQ P	1	404085916.3
EIQ C	1	112850157.1
EIQ E	1	1153561802

European Union 5 countries

Weight=6 Labour	Units	Value
Land under apples	Hectares	236181.38
Golden Delicious	Hectares	39541.02701
Red Delicious	Hectares	32290.1243
Granny Smith	Hectares	3933.853877
Jonagold	Hectares	1929.069
Boskoop	Hectares	1496.814
Gloster	Hectares	1692.252
Imperatore di Roma	Hectares	2517.336529
Others	Hectares	38605.79418
New Variety	Hectares	114175.1091
Production	Tonnes	6402405.893
Industry	Tonnes	794113.0676
Income ECUs	ECUs	378599185
Imports from NEUC	Tonnes	227107.34
Exports from NEUC	Tonnes	174765.52
Domestic consumption	Tonnes	5560007.102
Labour	Hours	155559099.1
EIQ Total	1	1663416225
EIQ P	1	402343977.4
EIQ C	1	112425681.1
EIQ E	1	1148646567

European Union 5 countries

Weight=10 Labour	Units	Value
Land under apples	Hectares	236181.38
Golden Delicious	Hectares	38839.38949
Red Delicious	Hectares	33411.61963
Granny Smith	Hectares	3484.660407
Jonagold	Hectares	1929.069
Boskoop	Hectares	1496.814
Gloster	Hectares	1692.252
Imperatore di Roma	Hectares	2517.336529
Others	Hectares	38185.93637
New Variety	Hectares	114624.3026
Production	Tonnes	6400550.724
Industry	Tonnes	794113.0676
Income ECUs	ECUs	374215056.2
Imports from NEUC	Tonnes	227107.34
Exports from NEUC	Tonnes	174765.52
Domestic consumption	Tonnes	5557621.635
Labour	Hours	155584927.7
EIQ Total	1	1659970274
EIQ P	1	401350361.4
EIQ C	1	112218176.2
EIQ E	1	1146401736

European Union 5 countries

Weight=3 PCE

	Units	Value
Land under apples	Hectares	236181.38
Golden Delicious	Hectares	49464.70361
Red Delicious	Hectares	24556.56082
Granny Smith	Hectares	3484.660407
Jonagold	Hectares	1929.069
Boskoop	Hectares	1496.814
Gloster	Hectares	1692.252
Imperatore di Roma	Hectares	2506.971313
Others	Hectares	39272.5411
New Variety	Hectares	111777.8078
Production	Tonnes	6403142.405
Industry	Tonnes	794113.0676
Income ECUs	ECUs	385946548.8
Imports from NEUC	Tonnes	227107.34
Exports from NEUC	Tonnes	174765.52
Domestic consumption	Tonnes	5557616.394
Labour	Hours	154508024.8
EIQ Total	1	1682145245
EIQ P	1	406221352.5
EIQ C	1	114081188.8
EIQ E	1	1161842704

European Union 5 countries

Weight=6 PCE	**Units**	**Value**
Land under apples	Hectares	236181.38
Golden Delicious	Hectares	38812.08927
Red Delicious	Hectares	29540.15844
Granny Smith	Hectares	3484.660407
Jonagold	Hectares	1929.069
Boskoop	Hectares	1496.814
Gloster	Hectares	1692.252
Imperatore di Roma	Hectares	2517.336529
Others	Hectares	41582.88801
New Variety	Hectares	115126.1124
Production	Tonnes	6402885.075
Industry	Tonnes	794113.0676
Income ECUs	ECUs	383835454.8
Imports from NEUC	Tonnes	227107.34
Exports from NEUC	Tonnes	174765.52
Domestic consumption	Tonnes	5560022.009
Labour	Hours	153608641.5
EIQ Total	1	1659727923
EIQ P	1	401375462.3
EIQ C	1	112220510.2
EIQ E	1	1146131951

European Union 5 countries

Weight=10 PCE	Units	Value
Land under apples	Hectares	236181.38
Golden Delicious	Hectares	38811.95411
Red Delicious	Hectares	31085.85257
Granny Smith	Hectares	3484.660407
Jonagold	Hectares	1929.069
Boskoop	Hectares	1496.814
Gloster	Hectares	1692.252
Imperatore di Roma	Hectares	2517.336529
Others	Hectares	39980.26073
New Variety	Hectares	115183.1807
Production	Tonnes	6402880.977
Industry	Tonnes	794113.0676
Income ECUs	ECUs	381768587.9
Imports from NEUC	Tonnes	227107.34
Exports from NEUC	Tonnes	174765.52
Domestic consumption	Tonnes	5560043.468
Labour	Hours	153788018.8
EIQ Total	1	1659331922
EIQ P	1	401288119.8
EIQ C	1	112187177
EIQ E	1	1145856626

European Union 5 countries

Weight=5 P	Units	Value
Land under apples	Hectares	236181.38
Golden Delicious	Hectares	39228.59987
Red Delicious	Hectares	34047.65148
Granny Smith	Hectares	3484.660407
Jonagold	Hectares	1929.069
Boskoop	Hectares	1496.814
Gloster	Hectares	1692.252
Imperatore di Roma	Hectares	2517.336529
Others	Hectares	36501.08285
New Variety	Hectares	115283.9139
Production	Tonnes	6403058.177
Industry	Tonnes	794113.0676
Income ECUs	ECUs	376599249.3
Imports from NEUC	Tonnes	227107.34
Exports from NEUC	Tonnes	174765.52
Domestic consumption	Tonnes	5560275.186
Labour	Hours	154539877.5
EIQ Total	1	1658588294
EIQ P	1	401129341.3
EIQ C	1	112125919.9
EIQ E	1	1145333032

European Union 5 countries

Weight=10 P	Units	Value
Land under apples	Hectares	236181.38
Golden Delicious	Hectares	38811.9265
Red Delicious	Hectares	38256.97027
Granny Smith	Hectares	3484.660407
Jonagold	Hectares	1929.069
Boskoop	Hectares	1496.814
Gloster	Hectares	1692.252
Imperatore di Roma	Hectares	2517.336529
Others	Hectares	32539.49532
New Variety	Hectares	115452.856
Production	Tonnes	6402885.075
Industry	Tonnes	794113.0676
Income ECUs	ECUs	369256666.9
Imports from NEUC	Tonnes	227107.34
Exports from NEUC	Tonnes	174765.52
Domestic consumption	Tonnes	5558976.164
Labour	Hours	154626290.9
EIQ Total	1	1657488064
EIQ P	1	400890260.3
EIQ C	1	112034294.9
EIQ E	1	1144563509

European Union 5 countries

Weight=5 C	Units	Value
Land under apples	Hectares	236181.38
Golden Delicious	Hectares	39621.93058
Red Delicious	Hectares	45649.1991
Granny Smith	Hectares	11413.39116
Jonagold	Hectares	1929.069
Boskoop	Hectares	1496.814
Gloster	Hectares	1692.252
Imperatore di Roma	Hectares	2517.336529
Others	Hectares	24776.65885
New Variety	Hectares	107084.7288
Production	Tonnes	6435659.98
Industry	Tonnes	794113.0676
Income ECUs	ECUs	394417902.6
Imports from NEUC	Tonnes	227107.34
Exports from NEUC	Tonnes	174765.52
Domestic consumption	Tonnes	5591250.898
Labour	Hours	155659777.9
EIQ Total	1	1721880709
EIQ P	1	419596157.6
EIQ C	1	115869286.3
EIQ E	1	1186415265

European Union 5 countries

Weight=10 C	Units	Value
Land under apples	Hectares	236181.38
Golden Delicious	Hectares	39822.40683
Red Delicious	Hectares	45649.1991
Granny Smith	Hectares	9969.330304
Jonagold	Hectares	1929.069
Boskoop	Hectares	1496.814
Gloster	Hectares	1692.252
Imperatore di Roma	Hectares	2517.336529
Others	Hectares	23864.52359
New Variety	Hectares	109240.4486
Production	Tonnes	6429924.092
Industry	Tonnes	794113.0676
Income ECUs	ECUs	389944477.8
Imports from NEUC	Tonnes	227107.34
Exports from NEUC	Tonnes	174765.52
Domestic consumption	Tonnes	5585108.608
Labour	Hours	155713574.8
EIQ Total	1	1705343720
EIQ P	1	414827828.7
EIQ C	1	114873472.2
EIQ E	1	1175642419

European Union 5 countries

Weight=5 E	Units	Value
Land under apples ha	Hectares	236181.38
Golden Delicious	Hectares	43305.36564
Red Delicious	Hectares	34047.65148
Granny Smith	Hectares	11307.1863
Jonagold	Hectares	1929.069
Boskoop	Hectares	1496.814
Gloster	Hectares	1692.252
Imperatore di Roma	Hectares	2517.336529
Others	Hectares	39188.70866
New Variety	Hectares	100696.9964
Production tonnes	Tonnes	6434628.419
Industry	Tonnes	794113.0676
Income ECUs	ECUs	431573854.6
Imports from NEUC tonnes	Tonnes	227107.34
Exports from NEUC tonnes	Tonnes	174765.52
Domestic consumption tonnes	Tonnes	5598076.521
Labour hrs	Hours	154418511.4
EIQ Total	1	1770461929
EIQ P	1	433387604.4
EIQ C	1	118863011.4
EIQ E	1	1218211313

European Union 5 countries

Weight=10 E	**Units**	**Value**
Land under apples ha	Hectares	236181.38
Golden Delicious	Hectares	39428.53212
Red Delicious	Hectares	38256.97027
Granny Smith	Hectares	9969.330304
Jonagold	Hectares	1929.069
Boskoop	Hectares	1496.814
Gloster	Hectares	1692.252
Imperatore di Roma	Hectares	2517.336529
Others	Hectares	31934.76447
New Variety	Hectares	108956.3113
Production tonnes	Tonnes	6429924.092
Industry	Tonnes	794113.0676
Income ECUs	ECUs	410242672.2
Imports from NEUC tonnes	Tonnes	227107.34
Exports from NEUC tonnes	Tonnes	174765.52
Domestic consumption tonnes	Tonnes	5588286.227
Labour hrs	Hours	154852638.6
EIQ Total	1	1707254723
EIQ P	1	415240836.5
EIQ C	1	115032071.9
EIQ E	1	1176981814